USE OF NON-INVASIVE SURVEYS TO VALIDATE PREDICTED BOBCAT (LYNX RUFUS) HABITAT DISTRIBUTION IN WISCONSIN FROM LANDSCAPE-SCALE GIS INFORMATION

by

LESLIE MAYES ADAMS

A Thesis

Submitted in partial fulfillment of the requirements of the degree

MASTER OF SCIENCE

IN

NATURAL RESOURCES (WILDLIFE)

College of Natural Resources

UNIVERSITY OF WISCONSIN

Stevens Point, Wisconsin

June 2009

APPROVED BY THE GRADUATE COMMITTEE OF

Dr. Eric Anderson, Committee Chairman
Professor of Wildlife Ecology and Management
College of Natural Resources

Dr. Tim Ginnett
Associate Professor of Wildlife
College of Natural Resources

Dr. Keith Rice
Professor of Geography
College of Letters and Science

Dr. Brian Sloss
Assistant Unit Leader
Wisconsin Cooperative Fishery Research Unit

This is dedicated to Zippie, my companion from middle school to graduate school, for her boundless love, infectious sense of humor, and for teaching me que será, será.

ABSTRACT

There has been mounting interest in Wisconsin to expand the bobcat harvest zone and a concomitant interest in increasing quota levels. However, bobcats are sensitive to over harvest and in Wisconsin current harvest boundaries are relatively arbitrary, are not defined by ecological boundaries, and do not adequately reflect the bobcat's statewide distribution. Management decisions are hampered by a lack of information concerning bobcat-habitat relationships, bobcat distribution, and bobcat abundance due to the lack of reliable survey methods. I developed a model to predict bobcat habitat distribution throughout Wisconsin and compared the effectiveness of non-invasive survey methods (winter track-counts, hair-snares, and a scat-sniffing detector dog). Prior to the hair-snare survey, I conducted scent trials with captive bobcats to determine which scent-lure elicited the most interest and a rubbing response.

For the first part of my study, I developed a predictive spatial distribution model using a multivariate distance statistic (Penrose distance) with adaptive kernel core areas estimated from over 1,000 locations from 10 radio collared female bobcats collected between 1991 - 1999 from three study sites in northern Wisconsin. The model identified 3 habitat variables that were highly correlated with bobcat habitat use: percent upland forest cover, percent forested wetland cover, and density of edge habitat. The model was applied statewide to hexagons of 4.5 km^2 (mean size of a bobcat core area) using more recent land-cover information (2001) to identify high, moderate, and low levels of bobcat habitat suitability. The model classified 20% of Wisconsin as highly suitable, 17% moderate, and 63% low. The predictive accuracy of the model was evaluated with 5 independent data sets including bobcat scat obtained by a detector dog, non-invasive hair snares, sighting data, harvest data and track surveys. Sample sizes were small, and lacked the power to detect any significant relationships between predicted habitat quality and any of the survey techniques. The only exception were sightings of bobcats south of the harvest zone

(N= 64) where 45% of the sightings occurred in highly and moderately suitable habitats which comprised only 27% of the area (χ_1^2 = 10.9, p < 0.001).

For the second part of my study, I compared detection rates, cost, and field time required to complete non-invasive techniques using winter track counts, hair-snares, and a detection dog trained to locate bobcat scat. I also tested for correlation of results between the 3 techniques. Each of 10 track count routes (16 km long) were surveyed with 2 hair snare transects (each comprised of 10 stations along a 4.5 km route) and one 2-km long detector dog transect. In addition, 1-2 additional hair snare transects were established between 5-16 km apart from the winter track route. Compared to winter track counts (only 5 could be run in 2007), the detector dog found 4 times the number of bobcats (12 vs 3) while only surveying 12.5% of the length of a track count survey. The hair snare method produced no detections of bobcats. The 37 hair samples that were collected were primarily from rodents, flying squirrels, and dogs. Including materials, labor, and travel, the detection dog was the most expensive method per transect ($397) while the winter track-counts were the least expensive ($180-$260). However, the cost per detection of the detector dog ($330) was comparable to the winter track counts ($300-433) due to its high detection rate. All three survey methods required comparable field times.

For the scent trials, I compared six scent lures: 1) Russ Carmen's Canine Call, 2) Lenon's Nature Call, 3) Lenon's Super All Call, 4) O'Gorman's Powder River Cat Call, 5) beaver castor, imitation catnip oil, and catnip, and 6) bobcat urine (BU) on 17 captive bobcats housed in 5 different facilities in Wisconsin and Florida. I recorded behavioral responses to the lures including sniff, rub, roll, and reach. A higher proportion of bobcats responded to scent lures than the control ($P<0.05$) however there was no difference ($P > .05$) in the proportion of bobcats that reacted when the 6 scent types were compared. Bobcats did sniff, rub, and roll more frequently on Lenon's Super All Call ($P<.05$) than the other lures. However, of the 17 bobcats, only 74% sniffed, 49% rubbed, and 41% rolled in response to the lure.

Predictive distribution models, combined with reliable non-invasive survey methods have the potential to aid wildlife managers in better understanding and managing bobcat populations that are difficult to survey on a landscape scale.

ACKNOWLEDGEMENTS

I thank the Wisconsin Department of Natural Resources (WDNR), the Citizen-based Monitoring Network of Wisconsin, the Wisconsin Trappers Association (WTA), the Wisconsin Bear Hunters Association, the Safari Club International, the University of Wisconsin-Stevens Point (UWSP) Student Research Fund, and the Dodge County Sporting/Conservation Alliance for providing funding for this project. I also thank the Green Bay Moose Lodge Rod and Gun Club for the Jack Massopust Memorial Scholarship.

My field work was supported by numerous volunteers from the WTA. In particular, I thank Scott McCauley and Lee Sillars for project support. I thank the Animal Haven Zoo, Bay Beech Sanctuary, Big Cat Rescue, Irvine Park Zoo, Jo Don Farms, New Zoo and Valley of the Kings Sanctuary for allowing access to their facilities and captive bobcats.

I thank Dr. Tim Ginnett and Dr. Keith Rice for providing advice and feedback on my research. Dr. Brian Sloss provided not only access to the Molecular Conservation Genetics Lab, but guidance and encouragement throughout my graduate career. Kevin Lawton shared his knowledge of GIS without hesitation. I thank my graduate advisor, Dr. Eric Anderson, for his enthusiasm, editorship, council and for allowing me the opportunity to work on a project that taught me ownership and independence. I am grateful for the chance to conduct research that is important to so many Wisconsin conservationists and sportsmen.

I thank my fellow graduate students, including Mandie Cyr, Chris Hamilton, Kate Schindler, Kim Skahan, Meaghan Proctor, and Trina Weiland. In particular, I thank Erin Cooney for sharing the ride of graduate school as officemates, housemates, field assistant, dog sitter, and friend. I thank Mitchell Jones, Trout, and Zippie for always giving me a laugh at the end of a long day. Finally, I thank my family for always supporting my endeavors, for cheering during the good times, and for guiding me through the hard times.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The bobcat (*Lynx rufus*) is the most widely distributed native felid in North America, ranging from British Columbia to southern Mexico. In the Great Lakes region they are largely restricted to wooded environments – primarily lowland conifer and recently clearcut aspen stands, although generally, habitat use is poorly understood (Lovallo and Anderson 1996, Rolley, et al. 2001). Bobcats are hunted and/or trapped in 39 states for their fur which is used for coats, trim, and accessories, with the spotted belly fur being the most valuable (Wolff and Hubert 1998). Currently in Wisconsin, the Wisconsin Department of Natural Resources (WDNR) issue a limited number of bobcat permits via a lottery system. Although harvest is restricted to the northern third of the state there is considerable interest in the species with less than 1% of applicants receiving a permit to harvest.

During the late 1970's and 1980's, the bobcat became the center of intense political and ecological debate as international trade in the endangered spotted cats was prohibited and commercial attention became focused on the non-threatened bobcat and lynx of North America. As harvest levels increased, concerns about a general lack of knowledge of bobcats and their population dynamics led to more restrictive management of the species throughout their range including Wisconsin (Rolley, et al. 2001).

Despite the increased efforts to manage and monitor the bobcat, the WDNR was petitioned by the Coalition for Bobcat Preservation in 1990 to list the bobcat as a state-threatened species. In the ensuing 4-year court battle, the Circuit Court, the Court of Appeals and finally the Wisconsin Supreme Court all concurred with the WDNR's decision not to list the species. However, throughout the legal proceedings independent experts as well as the courts themselves consistently noted that the available scientific evidence of the population size and its trend was inconclusive.

Because bobcats are cryptic by nature and comparatively rare due to their trophic position as predators, it is difficult to estimate their population size. The top research need identified by bobcat managers throughout the U.S. is the development of a reliable survey method (Bluett et al. 2001). Currently, the WDNR utilizes the Minnesota Furbearer Population Model to estimate the bobcat population size. This deterministic model relies on information about the size of the harvest and the age- and sex-structure combined with age-specific reproductive rates (determined from carcass collection) and estimated rates of non-harvest mortality. Winter track surveys (number of bobcat tracks encountered per km of snow-covered road) are used to adjust the general trend of the model to reflect changes in the number of tracks encountered. Unfortunately, the relationship between tracks encountered and bobcat population size is poorly understood and has not been rigorously tested.

In recent years, the bobcat harvest in Wisconsin has seen the highest take since 1960 (Dhuey and Olson 2006). There is an interest in expanding the area open to bobcat harvest, as well as increasing quota levels. However, the inconclusive nature of the population estimate, the unknown distribution of bobcats in the state, and the poorly understood habitat associations continue to hamper sound management decisions. My research focused on providing information on habitat association, distribution, and reliable survey methods for the species in Wisconsin.

In Chapter 1, I develop a model to predict the distribution of bobcat habitat in Wisconsin. Specifically, I (1) used data from radio-collared bobcats from 2 previous studies from 3 study sites in northern Wisconsin to (2) develop a predictive distribution map of bobcat habitat and (3) evaluated the accuracy of the model with independent data from non-invasive survey methods including winter track surveys, hair-snares, and a detector dog.

In Chapter 2, I compared the effectiveness of the non-invasive survey methods. Specifically, I compared the (1) detection rate, (2) cost, and (3) time required for winter track-count surveys, hair-snare surveys, and scat surveys with a trained detector dog. Finally, I compared my findings to previous studies that have employed these methods.

In Chapter 3, I conducted scent trials with captive bobcats to find a scent-lure that would be used as an attractant in the hair-snare surveys (Chapters 1 and 2). Specifically, I evaluated the efficacy of 6 different scent lure on 17 captive bobcats to entice interest and induce a rubbing response. I compared my findings to previous studies that (1) conducted scent trials with captive and wild felids, and (2) incorporated a scent lure as part of a hair-snare or scent-post survey for felids.

CHAPTER 1:

BOBCAT (*LYNX RUFUS*) HABITAT PREDICTIVE DISTRIBUTION MODEL IN WISCONSIN

ABSTRACT

There has been mounting interest in Wisconsin to expand the bobcat harvest zone and a concomitant interest in increasing quota levels. Current harvest boundaries are relatively arbitrary, are not defined by ecological boundaries, and do not adequately reflect the bobcat's statewide distribution. Predictive habitat models that are evaluated with independent data sets can aid wildlife managers by providing information about species distribution at a landscape scale. Research objectives were to: 1) model bobcat habitat suitability in Wisconsin, 2) apply the model statewide to predict potential bobcat distribution throughout Wisconsin, and 3) evaluate the predictive success of the model. I developed a predictive spatial distribution model using a multivariate distance statistic with adaptive kernel core areas estimated from over 1,000 locations from 10 radio collared female bobcats collected between 1991 - 1999 from three study sites in northern Wisconsin. The model was applied statewide using recent land-cover information to identify three levels of suitable bobcat habitat at the scale of 4.5 km^2, the mean size of a female bobcat core area. The predictive accuracy of the model was evaluated with independent data sets including bobcat scat obtained by a detector dog, non-invasive hair snares, sighting data, harvest data and track surveys. The frequency of bobcat sightings occurred more than expected in the Penrose distance category classified as moderate similarity to known bobcat core areas (χ^2 = 18.1, $p < 0.01$). This model may aid resource managers in Wisconsin by predicting bobcat habitat suitability at a coarse scale.

INTRODUCTION

There is no habitat model for bobcats in Wisconsin and the most recent range map of their actual or potential distribution is dated over 20 years (Bluett 1984). Currently, bobcats range throughout the northern region of the state (Rolley et al. 2001), extend into the central region (Dhuey and Olson 2007, Dhuey 2008), and have been recently documented in the southern portion of the state (R. E. Rolley, Wisconsin Department of Natural Resources, personal communication). Bobcats are hunted and trapped as part of an annual harvest in the northern third of the state (with State Highway 64 as the southern boundary). The status of bobcats in the northern region is estimated by a population model that uses age- and sex-structure and reproductive rates from the harvest and is adjusted by data collected from winter track surveys (Rolley et al. 2001). However, Rolley et al. (2001) warned that information derived from these methods should be interpreted with caution given the limitations associated with each technique. Even less is known about bobcats in the central and southern region due to an absence of harvest data and unreliable tracking conditions. There has been mounting pressure on the Wisconsin Department of Natural Resources (WDNR) to expand the bobcat harvest zone and increase harvest quotas, however the lack of information hinders management decisions. Better understanding the distribution of bobcats in the state will allow for the establishment of more biologically meaningful management units and may contribute towards a more reliable estimate of abundance.

Landscape modeling of habitat selection by animals has been extensively developed in the past decade (Manly et al. 2002). Predictive models based on species-landscape associations may be useful tools in wildlife management by identifying important habitat resources and predicting where species might occur throughout the landscape. The spatial representation of this information can significantly aid in management efforts (Mladenoff et al. 1995, Fernandez et al. 2006). Predictive habitat distribution models are a particularly valuable management tool for species that are difficult to survey such as bobcats due to their low density, wide dispersal, and elusive character (Anderson and Lovallo 2003).

Several statistical methods are available to create predictive models, however, most require defining both used and un-used (or available) habitat units (Guisan and Zimmermann 2000). Misclassification of habitat units can negatively affect model performance (Keating and Cherry 2004, Johnson et al. 2006, Pearce and Boyce 2006). Multivariate distance statistics do not require classification of used and unused habitats and have been well developed and evaluated (Clark et al. 1993, Knick and Rotenberry 1998, Hellgren et al. 2007). Several studies have used multivariate distance models to predict bobcat habitat on a landscape scale (Lovallo 1999). The Penrose distance statistic, for example, has been employed to model habitat similarity between known bobcat habitat and the rest of the landscape in which bobcat occupancy is unknown (Nielsen and Woolf 2002, Preuss and Gehring 2007).

My research objectives were to: 1) model bobcat habitat suitability in Wisconsin based on similarity to landscape variables associated with radio-collared bobcat core areas , 2) apply the model statewide to predict potential bobcat distribution throughout Wisconsin, and 3) evaluate the predictive success of the model with an independent data set. I developed a predictive spatial distribution model using a multivariate distance statistic with adaptive kernel core areas estimated from over 1,000 locations from 10 radio-collared female bobcats collected between 1991 - 1999 from three study sites in northern Wisconsin. The model was applied statewide using recent land-cover information to identify three levels of suitable bobcat habitat. The predictive accuracy of the model was evaluated with independent data sets including a survey conducted by a detector dog trained to locate bobcat scat, with non-invasive hair snares, sighting data, harvest data, and winter track counts.

STUDY AREA

To create the model, I utilized data from two previous studies conducted on three different study sites located in the bobcat harvest zone in the Northern Forest region of Wisconsin including the St. Croix National Scenic Riverway (SC), the Nicolet National Forest (NNF), and the Chequamegon National Forest (CNF) (Fig. 1).

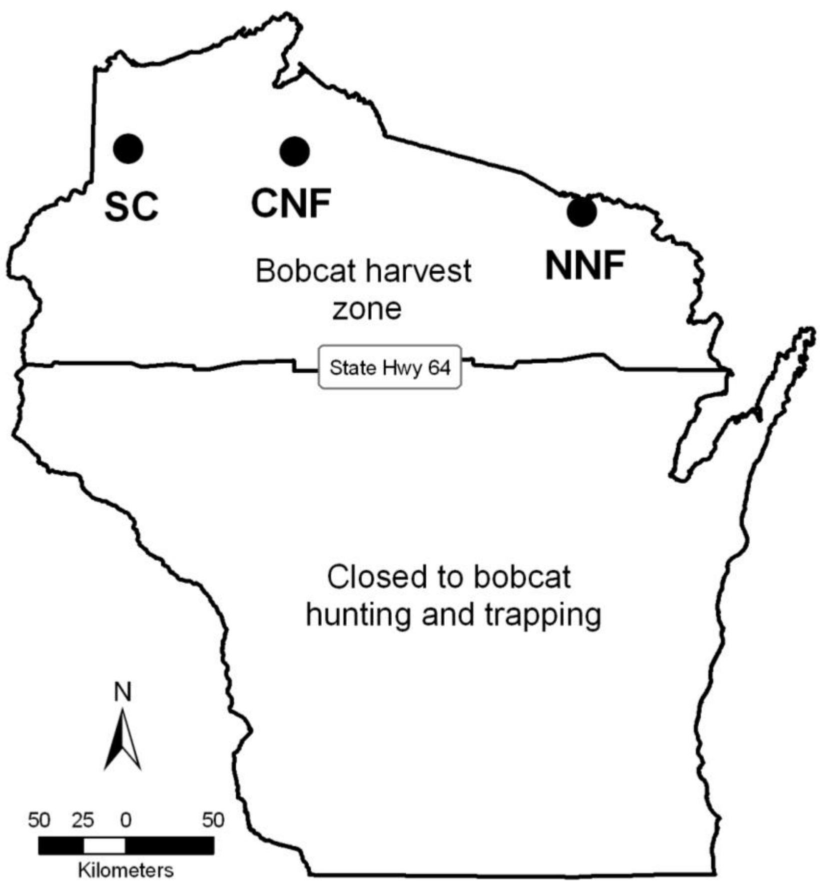

Figure 1. Locations of the three study areas used to model bobcat habitat in Wisconsin. Bobcats were radio-collared and re-located in the St. Croix National Scenic Riverway (SC), the Chequamegon National Forest (CNF), and the Nicolet National Forest (NNF).

Curtis (1959) described the northern forest as containing a wide variety of vegetation types. The forests are typically characterized by the presence of conifers, but a large hardwood component is also present. The lowland forests contain either conifer swamps with white cedar (*Thuja occidentalis*), black spruce (*Picea mariana*), and balsam fir (*Abies balsamea*) as the most common species, or hardwoods swamps dominated by black ash (*Fraxinus niger*) and alder (*Alnus spp*.). The uplands support jack pine (*Pinus banksiana*), red pine (*P. resinosa*), and white pine (*P. strobus*) as well as a hardwood component composed of mature aspen (*Populus tremuloides*), red maple (*Acer rubrum*), and white birch (*Betula papyrifera*). Topography was flat to moderately rolling and underlain with poorly drained ground moraine. The three study areas were comprised primarily of upland forest (61%-85%), forested wetland (5%-20%), non-forested wetland (2-15%), barren and shrubland (<1%-7%), grassland (2-5%), agriculture (< 1%-4%), open water (2%-4%), and urban (<1%) (Fig. 2) (Lovallo 1993, Gilbert 2003).

I modeled bobcat distribution throughout the state of Wisconsin including the central and southern non-harvest regions. In comparison to the three study areas, the state of Wisconsin is comprised of upland forest (37%), agriculture (31%), grassland (11%), forested wetland (7%), non-forested wetland (7%), open water (4%), barren and shrubland (<1%), and urban (2%) cover types

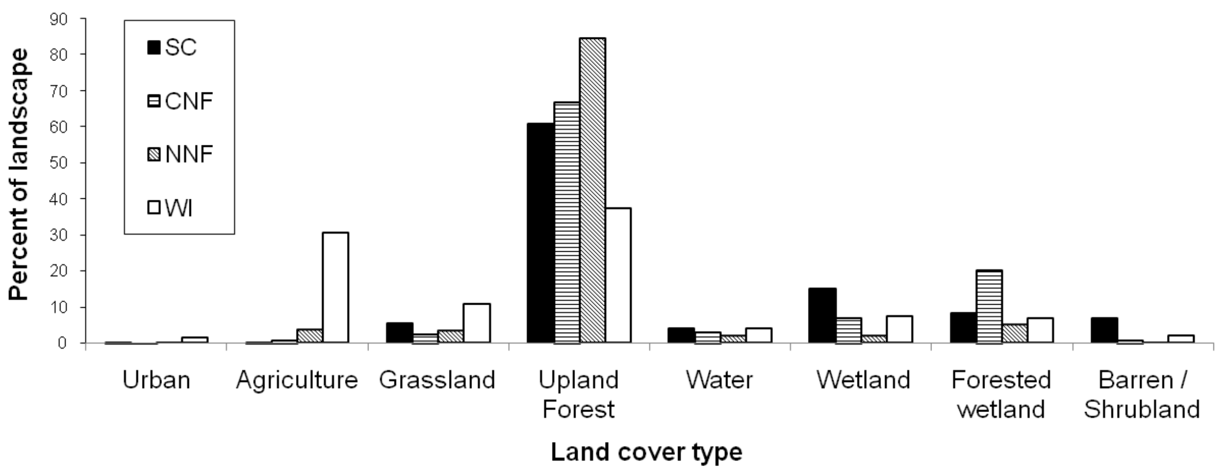

Figure 2. Landscape composition of the St. Croix National Scenic Riverway study area (SC), Chequamegon National Forest study area (CNF), Nicolet National Forest study area (NNF), and the state of Wisconsin (WI).

METHODS

Trapping and Radiotelemetry

I modeled landscape-level habitat relationships of bobcats by acquiring GIS-based data from known bobcat locations from four female bobcats (n = 78, 115, 261, and 288 locations) tracked from Jun 1991 to Sep 1992 in the SC (Lovallo 1993), from four female bobcats (n = 45, 57, 89, and 108 locations) relocated from Dec 1994 to Jun 1999 in the CNF (Gilbert 2003), and from two female bobcats (n = 39 and 82 locations) relocated from Dec 1992 to May 1993 in the NNF (Gilbert 2003). I used only female bobcats in modeling efforts to reduce redundancy and dependence associated with intersexual home range overlap and intrasexual home range overlap between males. Bobcats exhibit intersexual differences in prey use and habitat selection (Litvaitis et al. 1986, Lovallo and Anderson 1996, Lovallo et al. 2001, Koehler 2006) with male bobcat home ranges often two to three times larger than those of females. Anderson and Lovallo (2003) suggested that female home range size may be more closely tied to prey availability (which is a direct consequence of habitat attributes), whereas male home range size is more influenced by the number of mating opportunities (female home ranges) within the range.

Core area estimation

I modeled habitat suitability at the scale of the mean female core area (4.5 km^2) rather than individual locations because measurement error associated with radio-telemetry techniques can potentially influence conclusions drawn from a predictive model (Hunsaker et al. 2001). Core areas are relatively small areas within home ranges that receive increased use over an annual period (Samuel et al. 1985). I created 50% adaptive-kernel core areas with least squares cross validation (Seaman and Powell 1996) using Home Range Tools for ArcGIS (Rodgers et al. 2007) for the 10 female bobcats. The adaptive kernel algorithm provides contour-line polygons for user-specified percentages of annual or total relocations and measures core areas with less bias than home ranges (Seaman et al. 1999). In addition, the adaptive kernel method was chosen over other popular home range estimators such as Minimum Convex Polygon (MCP) because of its ability to calculate multiple centers of activity, its decreased sensitivity to outliers, and its ability to calculate boundaries based on complete utilization distributions (Millspaugh and Marzluff 2001). Bobcat locations included in core area estimation were separated by $\geq$ 24 hours to reduce potential for temporal autocorrelation and each bobcat had $\geq$ 30 relocations (Seaman et al. 1999). When core areas were comprised of multiple polygons, polygons that were $\leq$ 1 ha or contained $\leq$ 2 bobcat locations were removed from the analysis.

Land cover data

Bobcat radio-locations were collected during the early to mid-90s while habitat suitability was modeled for the present. To do this, I obtained satellite - derived land cover data from two different time periods, 1992 and 2001. The 1992 land cover data was used in the analysis of land cover variables associated with known bobcat core areas since the data were collected from 1991-1999 and the majority of re-locations collected from 1993-1994. Habitat suitability was modeled using the United States Geological Survey's (USGS) National Land Cover Database (NLCD) 2001 since it is the most recent state-wide land cover data available for Wisconsin (Homer et al. 2004). The 1992 Wisconsin Initiative for Statewide Cooperation on Landscape Analysis and Data (WISCLAND) dataset was derived from LANDSAT Thematic Mapper (TM) satellite imagery with 30 m resolution. I reclassified the original 42 cover classes into 8 biologically relevant classes (Table 1). Land cover data from 2001 was reclassified to the same 8 cover types. The locations of streams and lakes were obtained from the 1:24,000-scale WDNR Hydrography data layer (WDNR). Locations of roads were obtained from the U.S. Bureau of Census TIGER 1995 data layer. I calculated distance to water and distance to road from the center of a core area using ArcMap9.2 (Environmental Systems Research Institute, Inc., Redlands, Calif.). Contrast weight edge metrics were derived from both land-cover maps with user-specified contrast weights (Table 1). Contrast weights ranged from zero to one with lower scores indicating an edge between two minimally contrasting cover-types (e.g., grassland and agriculture) and a higher score indicating highly contrasting cover-types (e.g., urban and wetland).

Table 1. Contrast weight indices used to calculate edge metrics in landscape-level habitat models explaining presence of bobcats in Wisconsin, USA, with 0 = no contrast and 1 = high contrast

	Urban	Agriculture	Grassland	Upland forest	Water	Wetland	Forested wetland	Barren and shrubland
Urban	0	0.5	0.5	0.9	0.9	0.9	0.9	0.7
Agriculture	0.5	0	0.3	0.8	0.9	0.7	0.7	0.3
Grassland	0.5	0.3	0	0.8	0.9	0.7	0.7	0.3
Upland forest	0.9	0.8	0.8	0	0.9	0.8	0.7	0.8
Water	0.9	0.9	0.9	0.9	0	0.9	0.9	0.9
Wetland	0.9	0.7	0.7	0.7	0.9	0	0.6	0.7
Forested wetland	0.9	0.7	0.7	0.3	0.9	0.6	0	0.5
Barren and shrubland	0.7	0.3	0.3	0.5	0.9	0.7	0.5	0

Model variable selection

To select variables for modeling, I first created a grid of 31,146 non-overlapping hexagons of 4.5km^2 (an area equal to the average kernel core area of the 10 female bobcats) that covered the state of Wisconsin (WI). I then calculated 164 landscape variables within each hexagon with 2001 land cover data using the Spatial Statistics by Regions interface of Patch Analyst Grid 0.9.8 extension (Kaukinen et al. 2007) with the FRAGSTATS interface (McGarigal et al. 2002). Landscape variables were grouped into seven categories based on the type of spatial statistic being measured (Table 2).

I reduced the number of variables for modeling based on univariate statistics and presumed importance to bobcats. First, to satisfy the assumption of normality, I log-transformed cover-type proportions and used a value of 0.001 for null proportions (Aebischer et al. 1993).

Table 2. Habitat (class) and landscape variables calculated for potential use in modeling bobcat habitat in Wisconsin, USA, 2000. Variables were caluclated using the Spatial Statistics by Regions interface of the Patch Analyst Grid 4.0 extension to ArcMap Geographic Information System 9.2.

Calculation[a]	Acronym	Variable	Unit
Area metrics			
Class	%LAND	% of landscpe	%
Class-Landscape[b]	LPI	Largest patch index	%
Patch metrics			
Class-landscape	NumP	Number of patches	no.
Class-landscape	MPS	Mean patch size	ha
Class-landscape	PSCov	Patch size coefficient of variation	%
Edge metrics			
Class-landscape	CWED	Contrast weighted edge density	m/ha
Class-landscape	ED	Edge density	m/ha
Shape metrics			
Class-landscape	MSI	Mean shape index	
Class-landscape	AWMSI	Area weighted mean shape index	
Class-landscape	LSI	Landscape shape index	
Class-landscape	DLFD	Double log fractal dimension	
Core area metrics			
Class-landscape	C%LAND	Core area percentage of landsape	%
Class-landscape	CAD	Core area density	no./100 ha
Class-landscape	TCAI	Total core area index	%
Class-landscape	MCAI	Mean core area index	%
Class-landscape	MCA1	Mean core area per patch	ha
Class-landscape	MCA	Mean core area	ha
Class-landscape	CACoV	Core area coefficient of variation	%
Class-landscape	CACV1	Patch core area coefficient of variation	%
Diversity metrics			
Landscape	SDI	Shannons diversity index	
Landscape	SHEI	Shannon's eveness index	
Landscape	MSIDI	Modified Simpsons diversity index	
Landscape	MSIEI	Modified Simpsons eveness index	
Landscape	PR	Patch richness	no.
Landscape	PRD	Patch richness density	no./100 ha
Nearest neighbor metrics			
Class-landscape	MNN	Mean nearest neighbor distance	m
Distance to water[c]			m
Distance to road[c]			m

[a] Class variables were calculated for grassland, upland forest, open water, wetland, forested wetland, and barren/shrubland land-cover types.

[b] Landscape refers to the total composition of habitats within each hexagon.

[c] Calculated with Spatial Analyst in ArcMap 9.2.

Second, within each cover type I conducted nonparametric Spearman rank correlations for variables in each of the 7 statistical categories. I retained variables most representative of the group (i.e., most correlated with others within the group). When ties occurred, I selected the variable with the greater presumed biological importance to bobcats based on past research. This resulted in 54 potential landscape variables. I reduced these potential variables to 19 by retaining the log-transformed proportion of each cover type in addition to the variable most correlated to others within each habitat class. I eliminated the two variables associated with the urban cover type because it did not occur in bobcat core areas. I also eliminated the two variables associated with the agriculture cover type because it occurred in only 4 of 10 (≤ 40%) bobcat core areas. This resulted in the selection of nine variables for modeling (Table 3). I performed all statistical analysis (α = 0.05) using SPSS software (SPSS 2007).

Table 3. Nine variables retained for modeling bobcat habitat in Wisconsin, USA.

Variable
Distance to road
Distance to water
Edge density
Percent of upland cover
Percent of forested wetland cover
Percent of wetland cover
Percent of grassland cover
Percent of barren/shrubland cover
Percent of water cover

Habitat model

I created a model of bobcat habitat for Wisconsin based on the nine landscape characteristics from female bobcat core areas (Table 3). I measured the landscape similarity between the core areas and the rest of Wisconsin with a modified Penrose distance statistic. The Penrose distance was employed over other distance statistics because it allowed the inclusion of negative values that resulted from log-transforming the habitat proportions. The Penrose distance for each WI hexagon (n = 31,146) was calculated as:

$$P_{ij} = \sum_{k=1}^{p} \frac{(\mu \quad - x \quad)^2}{pV}$$

where μ was the mean habitat vector of the landscape variables from female bobcat core areas (n=10) calculated with 1992 land cover data, x was the value of the landscape variables from a WI hexagon calculated from 2001 land cover data, p was the number of habitat variables evaluated (n = 9) and V

was variance of the mean habitat vectors of bobcat core areas (Manly 2005). Each WI hexagon was evaluated relative to the mean habitat vector of known female bobcat core areas and received a Penrose distance value. A Penrose distance close to zero indicated high similarity to mean habitat vectors of female bobcat core areas while large Penrose distances indicated less similarity to mean habitat vectors of female bobcat core areas. I classified Penrose distances into three qualitative habitat categories based on similarity to known bobcat core areas: high, moderate, and low. To delineate Penrose classes, I first binned the Penrose distance values of bobcat core areas based on one integer increments from 0-5 and then created a histogram of the frequency of Penrose values within each bin. From this, I estimated a curve based on a half normal distribution and calculated a maximum likelihood estimator (MLE) as: $\hat{\sigma}^2_{MLE} = \frac{\sum x_i^2}{n}$ where x_i are the Penrose values of bobcat core areas and n is the number of bobcat core areas. From this, I calculated the Penrose distance values where: (i) 75% of the core areas fell below (high similarity) and (ii) 75-100% of the core areas occurred (moderate similarity). Hexagons with a Penrose distance greater than the highest core area value were classified as low similarity. The relative importance of each landscape variable to the calculation of the Penrose distance was determined by correlating Penrose distance to each landscape variable.

Model Evaluation

Hair snare survey **-** I conducted hair snare surveys from Jun – Aug 2008 to investigate the presence and distribution of bobcats throughout Wisconsin. I established 48 hair snare transects in northern, central, and southwestern Wisconsin (Fig. 3). An additional 41 transects were established by citizen scientists in northern and central Wisconsin. Each transect was 4.5 km long and comprised of 10 hair snares spaced 500 m apart along secondary roads and trails. For efficiency, I established groups of 2-4 transects within the same geographical location.. Thirty six of the 48 transects were established on

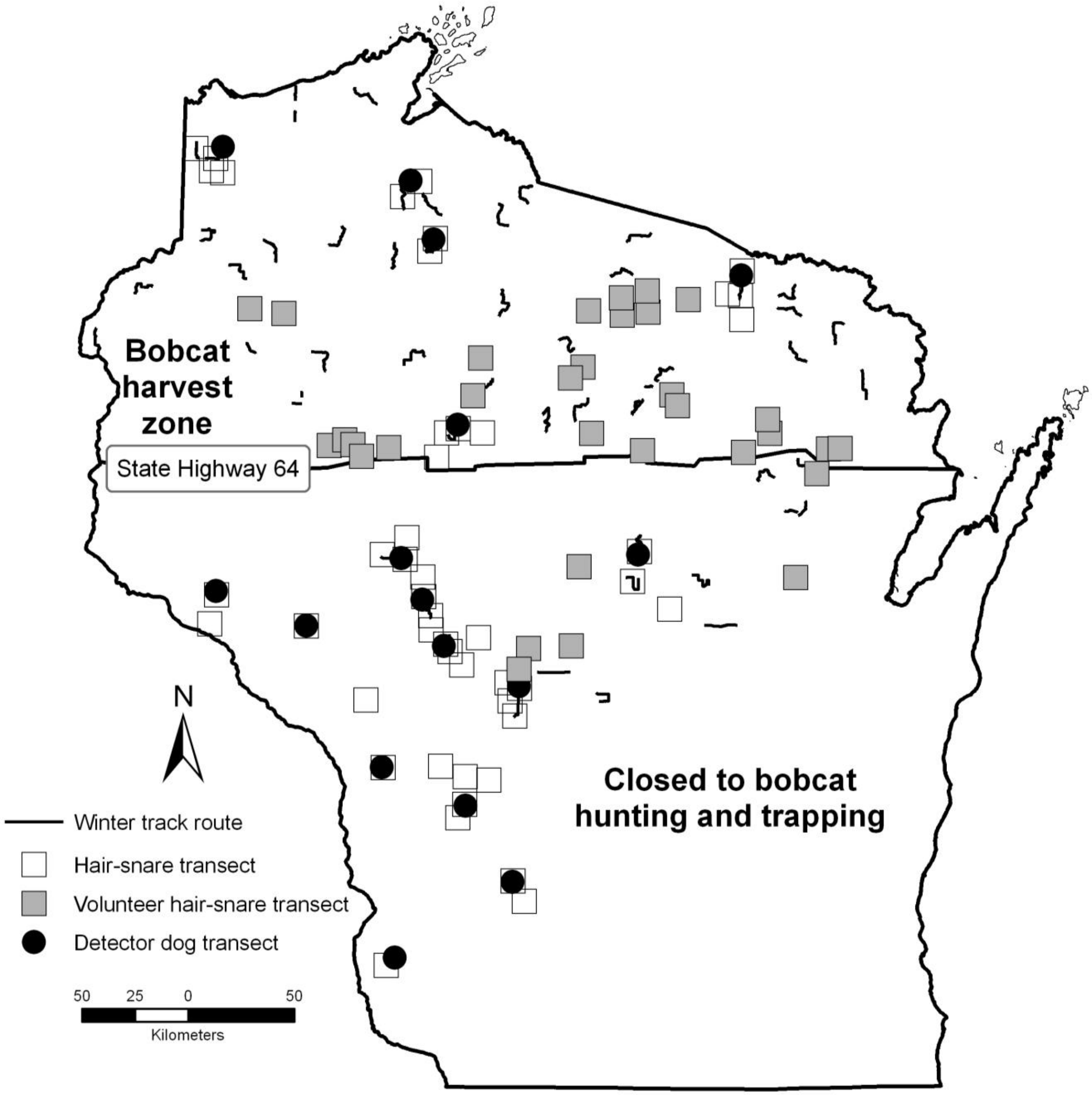

Figure 3. Map of winter track routes (n=50), hair-snare transects (n=48), volunteer hair snare transects (n=41), and detector dog transects (n=16) surveyed for bobcats during Jul – Aug of 2008 in Wisconsin, USA

or near pre-existing 16km long winter track routes to facilitate a subsequent comparative analysis of survey techniques (Chapter 2). Two hair snare transects overlapped the beginning and end 4.5km long portions of a winter track route (i.e., overlapping a 9 km or 56% portion of winter track routes). One to two additional hair snare transects were established between 5-16 km apart from the winter track route. A minimum distance of 5 km between transects was instituted to reduce detecting the same individual bobcat on multiple transects. No winter track routes existed in southwest Wisconsin; therefore, routes (n=12) were established in this region based on availability of public and private land where I could obtain permission to erect hair snares. Snares were placed up to 10 m from the road in public use areas. Hair snares consisted of a shelf bracket mounted to a tree at a height of 0.3 m above the ground with a 30.5 x 12.7 cm piece of landscape edging fastened to the bracket arm perpendicular to the tree. A 20.3 x 12.7 cm glue board (Catchmaster, AP&G Co., Brooklyn, New York) was secured to the underside of the edging mounting tape and baited with 2 ml of Super All Call (Lenon's Animal Lures, Gulliver, Mich.). Also, 2 ml of Carmen's Canine Call (R. Carmen, New Milford, PA.) was deposited on a branch within 5 m of the snare as a call lure. Glue was chosen for this study because of: 1) large quantities of hair samples recovered from glue based snares during trials with captive cougars (E. Anderson, University of Wisconsin- Stevens Point, personal communication) and 2) the ease with which citizen volunteers could re-cover sampled glue boards with the original release paper to minimize contamination and facilitate delivery by mail. Lures were chosen based on results from scent trials with captive bobcats prior to the field season (Chapter 3). For a visual attractant I hung a compact disc within 3 m of the hair snare that hung approximately 1 m above ground. Hair snares were left in place for 4 weeks and checked and re-baited after 2 weeks. Glue boards with deposited hairs were collected and replaced with a new glue board. Collected glue boards were covered with their original release paper, placed in manila envelopes and stored in a cool dry place until genetic analysis.

Genetic analysis of hair samples was performed at the Molecular Conservation Genetics Lab of the Wisconsin Cooperative Fishery Research Unit (UW-SP, Stevens Point, WI). DNA was extracted from samples using the Qiagen DNeasy® Blood and Tissue Kit (Qiagen Inc., Valencia, CA).

When possible, a minimum of 15 hairs and no more than 25 hairs were used as source tissue and the manufacturer's recommended protocol was followed except five separate final elutions were performed with 50 μLof TLE to ensure adequate DNA quantity. Following extraction, all extractions were checked for DNA quality (i.e., molecular weight) by electrophoresing an aliquot of DNA in a 0.7% agarose gel with ethidium bromide. The gel was visualized using UV light and the molecular weight of each sample compared to a known standard (Hyperladder™ I, Bioline, Inc., Randolph, MA). DNA quantity was determined using a Nanodrop® ND-1000 spectrophotometer (Nanodrop Technologies, Wilmington, DE). Previous studies of felid species identity have shown the DNA sequence of the universal portion of the mitochondrial 16S rRNA gene provides for diagnostic species identification (Foran et al. 1997; Johnson et al. 1998; Mills et al. 2000). I used the 16S rRNA primers (16S-1F and 16S-4R) of Hoelzel and Green (1992) to amplify an approximately 376 base pair portion of the 16S rRNA gene for species identification following the reaction conditions of Johnson et al. (1998). Amplicons were checked for single bands using a 2% agarose-TBE gel with ethidium bromide and visualized on a UV light. All successful amplifications were purified using Millipore MultiScreen® $PCR_{\mu96}$ MultiScreen filter plates (Millipore Corp., Billerica, MA, USA) and the manufacturer's recommended protocol. DNA sequencing was performed using ABI BigDye® v3.1 (Applied Biosystems, Inc., Foster City, CA, USA) and one of the PCR primers, cleaned of unincorpated dideoxynucleotides using Millipore Montage Seq96 Sequencing Reaction cleanup kit (Millipore, Inc.), and sequenced on an ABI 3730 DNA Analyzer (Applied Biosystems). Sequence data was proofed in Geneious (Drummond et al. 2007), and compared to known species sequences in GenBank (Benson et al. 2005).

Transects were overlaid on the Penrose distance map and assigned a Penrose value based on the surrounding habitat. If a transect passed through more than one hexagon, a weighted mean Penrose value was calculated based on the percentage of the transect that passed through each hexagon. I calculated frequency distributions of the percentage of hairs that were detected in each Penrose distance class (high, moderate, or low similarity). I then determined if locations of hairs were detected more or less than expected within each Penrose distance class using Chi square goodness of fit test (Neu et al. 1974). Hairs were expected to be located in proportion to the availability of habitat in each Penrose distance class. The three classes of Penrose distance were delineated using only n=10 bobcats; this small sample could have introduced bias in the classification of Penrose distance classes and subsequently decreased the power of the goodness of fit test. Thus, in addition to using a goodness of fit test based on Penrose classes, I also compared the actual Penrose distance values of transects in which scats and hairs were detected to transects in which scats and hairs were not detected using the Student t-test (Zar 1999). Likewise, I compared Penrose values of transects in the no-harvest zone in which hairs and scats were detected to transects in the no-harvest zone in which hairs and scats were not detected with the Student t-test.

Scat survey - I hired a detector-dog-handler team (Kristin Winford, Ashland, Wisconsin) that searched 16-2km transects along secondary roads and trails for bobcat scat in Jul 2008 that overlapped a 2 km portion of the hair snare transects. Detailed descriptions of training and field protocols for the detection dog can be found in Chapter 2. The dog-handler team surveyed each transect between dawn and midday and searched between 2-4 hours. When the dog located a potential bobcat scat, the dog alerted the handler by sitting next to the scat and looking at the handler. Scats were collected up to 30 m away from the transect line and either immediately frozen if possible (Constable et al. 2001), or deposited in 95% ethanol (Oka and Takenaka 2001).

To ensure all potential bobcat scats were collected, the handler also collected scats in which the detector dog did not alert, but showed a high interest. Scat locations were recorded on a 1:24,000-scale aerial photo of the transect. Scats were processed by the Molecular Conservation Genetics Lab of the Wisconsin Cooperative Fishery Research Unit (UW-SP, Stevens Point, WI) for species identification. DNA extractions were performed in a controlled environment using the QIAamp® DNA stool mini kit (QIAgen, Inc., Valencia, CA) and the manufacturer's 'Protocol for Isolation of DNA from Stool for Human DNA Analysis'. Each scat sample was extracted five times with samples from across the length of the scat. All extractions were performed under conditions aimed to minimize the potential for contamination among samples. As such, only a single fecal sample was allowed out of storage at a given time, disposable, scalpel blades were used to scrape the recommended amount of fecal material from the scat and a new blade was used for each scat, filtered tips were employed for all liquid handling, and all surfaces were wiped down between samples using a 5% bleach solution and lab bench paper was replaced for each new scat sample. 16S rRNA amplification was as described previously for hair samples. When multiple products were observed on the 2% agarose check gel, gel-purification of the target product (~376 bp) was performed in a 2% agarose TAE gel with the Eppendorf PerfectPrep® Gel Cleanup kit (Eppendorf North America, Westbury, NY, USA) following the manufacturer's recommended protocol.

Transects were overlaid on the Penrose distance map and assigned a Penrose value as described for the hair snare transects. I then determined if locations of scats were detected more or less than expected within each Penrose distance class using Chi square goodness of fit test (Neu et al. 1974). Scats were expected to be located in proportion to the availability of habitat in each Penrose distance class. As for the hair snare transects, I also compared the actual Penrose distance values of transects in which scats were detected to transects in which scats were not detected using the Student t-test (Zar 1999). Likewise, I compared Penrose values of transects in the no-harvest zone in which and scats were detected to transects in the no-harvest zone in which scats were not detected with the Student t-test.

Sighting data - I compiled bobcat locations collected outside of the harvest zone during 2002-2009 (n=65) from camera and live observations, incidental captures, roadkill and encountered tracks. I buffered each location by 4.5 km^2 (mean area of 50% kernel core area of 10 female bobcats), overlaid the locations on the Penrose map, and calculated the Penrose distance of each sighting by averaging the Penrose value of each hexagon the buffered location intersected. I then calculated frequency distributions of the percentage of sightings occurring in each Penrose class. I then determined if sightings were located more or less than expected within each Penrose distance class using Chi square goodness of fit test and a Bonferroni z-test to identify categories that were statistically different from what was available (Neu et a. 1974). Sightings were expected to be located in proportion to the availability of habitat within each Penrose distance class outside of the harvest zone.

Harvest data - I utilized an independent set of harvest data from the WDNR collected during the 1997-2007 harvest season (Dhuey and Olson 2007) to verify the accuracy of the model in the harvest zone. Harvest locations were recorded at the level of Deer Management Units (DMU) and Penrose values were calculated for each DMU by averaging all Penrose values within the DMU. The mean area of a DMU was 1,061 km^2. Within the harvest zone, I conducted nonparametric Spearman rank correlations between the mean DMU Penrose distances and harvest rates of each DMU.

Winter track routes - I utilized an independent set of track data from the WDNR collected during 1998-2008 from 50 furbearer winter track survey routes. Forty 16 km long winter track routes were established in northern Wisconsin in 1977 and an additional 10 routes were established in 1998 in central Wisconsin. One to two routes were established in each county, being at least 16km apart and 16km long and having good habitat of mixed aspen, alder, and conifers. Generally, large areas of unbroken pine and hardwoods were avoided. Roads that were least likely to be plowed following a storm and with minimal traffic were chosen for transects. The number of observed bobcat tracks was documented along the routes by wildlife managers and researchers on the first day after a snowfall, allowing one night for track registry (Dhuey 2008). I calculated Penrose distances for track routes by averaging the Penrose distance values of hexagons that intersected the route. Correlation between number of tracks encountered along the route and the mean Penrose distance of the route was tested with nonparametric Spearman rank. I calculated frequency distributions of the number of winter track routes in each Penrose distance class on which tracks were detected. I then determined if tracks were detected more or less than expected within each Penrose distance class using Chi square goodness of fit test (Neu et al. 1974). Tracks were expected to be detected in proportion to the number of routes in each Penrose distance class. Again, because of potential bias in the classification of Penrose distance classes due to small sample size of bobcat core areas, I compared the mean Penrose values of transects in which tracks were detected to transects in which tracks were not detected using the Student t-test (Zar 1999).

RESULTS

Habitat model

Bobcat core area hexagons were comprised of over four times more wetland and two times more forested wetland than the state-averaged hexagons. Hexagons from the entire state comprised 36 times more agriculture, six times more urban, and three times more water than bobcat core areas. Within the harvest zone, bobcat core areas comprised over three times more wetland than the surrounding hexagons. Hexagons in the harvest zone comprised 13 times more agriculture, five times more water, and four and a half times more urban than bobcat core areas. Across the state, all 9 model variables were significantly correlated with Penrose distance (Table 4).

Table 4. Mean values of nine habitat variables used for modeling bobcat habitat in Wisconsin, USA (2001) and the correlations between each variable and Penrose distance (PD). Values were calculated from 50% kernel core areas of 10 radio collared female bobcats and from within hexagons (n=31,146) of a hexagon grid overlaid on WI. The mean habitat vectors were calculated as the mean values of the nine variables within bobcat core areas.

Variable	$\bar{x}$ vector		WI hexagons		Correlation between all hexagons and PD
	Mean	SE	Mean	SE	
Distance to road	442.63	64.79	313.97	1.74	-0.03**
Distance to water	275.13	36.06	344.16	1.97	0.11**
Edge density	111.14	7.32	108.43	0.20	-0.41**
% of barren/shrubland cover	1.38	0.74	1.02	≤ 0.01	-0.17**
% of forested wetland cover	18.55	3.37	9.15	≤ 0.01	-0.42**
% of wetland cover	14.27	2.93	3.30	≤ 0.01	-0.30**
% of water cover	0.94	0.27	2.87	≤ 0.01	-0.25**
% of upland cover	62.22	3.86	39.10	≤ 0.01	-0.60**
% of grassland cover	2.46	0.82	1.65	≤ 0.01	-0.24**

** indicates significance at the 0.05 level

Penrose distances of bobcat core areas ranged from 0.37 to 4.94 ($\bar{x}$ = 2.05, SE = 0.45, n = 10) while WI hexagons ranged from 0.20 to 201.23 ($\bar{x}$ = 10.19, SE = 0.09, n = 31,147). The MLE for the estimated curve of bobcat core area Penrose distances was calculated to be $\hat{\sigma}^2_{MLE} = 2.47$. From this, I estimated a Penrose distance value below which 75% of the core areas fell (PD ≤ 2.83) as hexagons of high similarity. The remaining 75-100% of the curve was considered to represent hexagons of moderate similarity (PD =2.83 - 4.94). Hexagons with a PD value > 4.94 (maximum Penrose distance of known bobcat core area) were considered as areas of low similarity. Throughout Wisconsin, 20% of the hexagons had Penrose distances that indicated high similarity, 17% of hexagons had Penrose distances that indicated moderate similarity, and 63% hexagons had Penrose distances that indicated low similarity (Fig.4).

Model evaluation

Hair snares - Eleven of 48 (23%) of hair snare transects were established in areas of high similarity to known bobcat core areas, 15 (31%) of hair snare transects were established in areas of

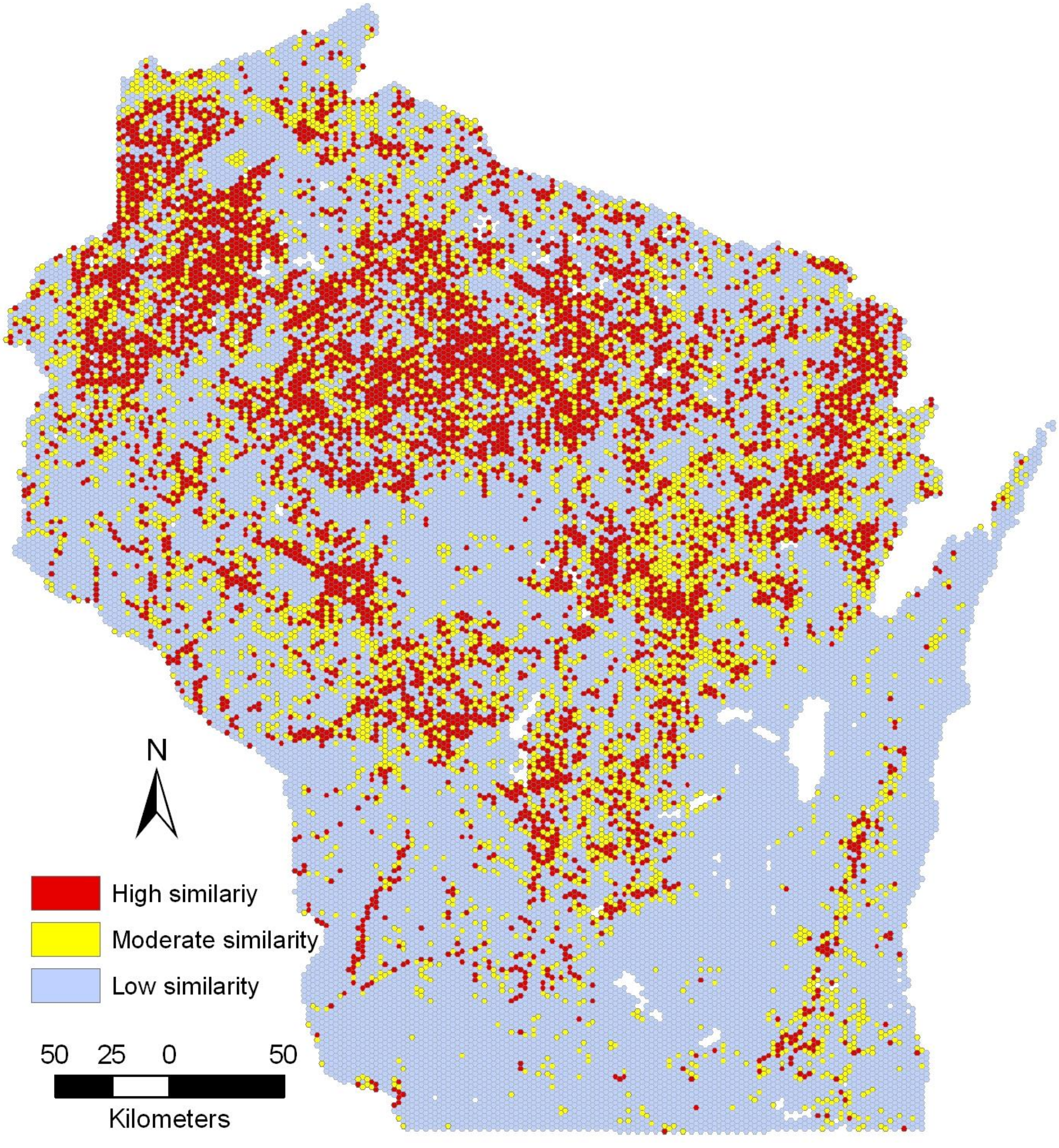

Figure 4. Penrose distance map depicting habitat similarity between core areas of radio-collared adult female bobcats (n=10) and the state of Wisconsin, USA (n=31,140 hexagons).

moderate similarity, and 22 (46%) of transects were established in areas of low similarity. Bobcat hairs were detected on only two snares within 1 of 48 (2%) transects. Bobcat hair was detected on 2 of 41 (5%) volunteer transects, however due to deviances from protocol in hair collection methods that led to high probabilities of contamination, samples collected by volunteers were not used for further analysis in model evaluation. The small sample size of hair samples precluded their use for model evaluation.

Scat detection dog - Four of 16 (25%) scat transects were in areas of high similarity, 4 (25%) were in areas of moderate similarity, and 8 (50%) were in areas of low similarity. Scats were detected on 38% of transects (n=6) in all three Penrose classes and were not located more or less than expected within each Penrose distance class (χ^2_3 = 0.33, p = 0.85). Penrose distances of transects in which scats were detected ($\bar{x}$ = 4.8, SE = 1.13, n = 6) were not significantly different from transects in which scats were not detected ($\bar{x}$ = 5.26, SE = 0.78, n = 10), p =0.74. In the central and southern portion of the state where no bobcat harvest occurs, the Penrose distance of transects in which scats were detected ($\bar{x}$ = 3.8, SE = 1.49, n = 3) were also not significantly different from transects in which scats were not detected ($\bar{x}$ = 5.1, SE = 0.97, n = 8), p = 0.51.

Sightings - Forty five percent of bobcat sightings occurred in the high and moderate similarity classes (Table 5). Locations of bobcat sightings did not occur randomly relative to Penrose distance classes (χ^2_3 = 18.1, p < 0.001). Bobcat sightings occurred more frequently than expected in hexagons

Table 5. Bobcat sightings in each Penrose class outside of the bobcat harvest zone of Wisconsin, USA (1997-2009)

Penrose distance class	Number of Sightings (%)	Percentage of available hexagons
High similarity (0-2.89)	7 (11%)	12%
Moderate similarity (2.9-4.94)	22 (34%)	15%
Low similarity (> 4.94)	35 (55%)	73%

with Penrose distances of moderate similarity and less frequently than expected in hexagons with a Penrose distances of low similarity.

Harvest - Within the bobcat harvest zone, mean Penrose distances of DMUs were not correlated with average bobcat harvest rates from 1997-2007 (Spearmans rho = 0.16, p = 0.24). Statewide, mean Penrose distances of DMUs were negatively correlated with average bobcat harvest rates from 1997- 2007 (Spearmans rho = -0.43, p < 0.00). As the habitat became more similar to bobcat core area habitat, the higher the average bobcat harvest was.

Winter track routes - Two of 50 (4%) winter track routes were in areas of high similarity, 22 (44%) winter track routes were in areas of moderate similarity, and 26 (52%) of routes were in areas of low similarity. Between 1997 and 2008, bobcat tracks were detected on 68% of routes (n=34) in all three Penrose classes and were not detected more or less than expected within each Penrose distance class (χ^2 = 0.12, p = 0.73). The average Penrose distances of routes in which bobcat tracks were detected ($\bar{x}$ = 5.47, SE = 0.37, n = 34) was not significantly different from routes in which tracks were not detected ($\bar{x}$ = 5.46, SE =0.75, n = 14, p =0.99). The mean number of tracks encountered on routes in high and moderate similarity classes ($\bar{x}$ = 0.83, SE = 0.32) was not significantly different than the mean number of tracks encountered in the low Penrose distance class ($\bar{x}$ = 0.77, SE = 0.12, p = 0.86). There was no correlation between Penrose distance of winter track routes and the average rates of encountering bobcat tracks from 1997-2008 (Spearmans rho = -.17, p = 0.25).

DISCUSSION

I used a multivariate distance statistic to model bobcat habitat which did not require the classification of used and unused habitats. The Penrose distance statistic identified areas of Wisconsin in terms of similarity to known bobcat core areas based on landscape variables. Percentage of upland forest, percentage of lowland forest, and edge density were most correlated to Penrose distance indicating their importance in determining bobcat habitat quality. These variables have been identified as important indicators of bobcat habitat in other studies as well (Pruess and Gehring 2007, Nielsen and Woolf 2002, Woolf et al. 2002, Lovallo 1999).

The accuracy of the Penrose distance model was only collaborated by sighting data in the non-harvest zone. Forty-four percent of the sightings occurred in high and moderate similarity classes while these two classes comprised only 27% of the available hexagons. In particular, 34% of sightings occurred in hexagons classified as moderate similarity while this class comprised only 15% of the landscape. Two factors that limit the usefulness of sighting data may be that (i) it may contain uncertainty and error, (ii) it is typically not random (Agee et al. 1989, Stoms et al. 1993, Palma et al. 1999). I addressed these limitations by only using sighting locations that were authenticated by WDNR biologists and buffering these locations by 4.5 km^2

The mean Penrose distance of transects on which bobcat scats was detected (n=6) had moderate similarity to known bobcat core areas while the mean Penrose distance of transects on which no scats were detected (n=10) had low similarity to known bobcat core areas. However, scats were not detected more or less than expected within each Penrose distance class. These results should be interpreted cautiously since the low power of the test (n=16 transects surveyed) may have been insufficient to detect a significant relationship (Zar 1999).

Penrose distances were not correlated to harvest levels. There were several limitations associated with using harvest data to evaluate the Penrose distance model: (i) harvest data was only available at the scale of management unit, (ii) locations of harvest data are often not accurately reported, and (iii) a successful harvest may be the result of hunter or trapper effort and/or accessibility and not habitat quality. When analyzed on a statewide scale, management units in which bobcat harvest was permitted were correlated with lower Penrose distances indicating that the current harvest takes place in areas of high similarity to known bobcat core areas while management units in which a harvest does not take place are correlated with higher Penrose distances, or lower similarity. However, 4 of the 84 (5%) of the DMUs within the non-harvest zone had mean Penrose distances indicating high similarity to known bobcat core areas (DMUs 57, 59D, 63B, and 73D), and 6 had mean Penrose distances indicating moderate similarity (DMUs 27, 54C, 55, 58, 68A, and 69). The difference in mean Penrose distance values between the harvest and non-harvest zone could indicate that bobcats south of the harvest zone select habitat based on different landscape variables than bobcats in the northern harvest zone. The poor performance of the model, even when evaluated against evidence only from the harvest zone, suggests the model may be inadequate to correctly identify bobcat habitat on anything more than a coarse level.

There was no relationship between Penrose distance and the number of bobcat tracks encountered on winter track routes. Low rates of encounter combined with variable tracking conditions and inconsistency of tracking personnel led to small sample sizes; mean number of tracks encountered for all transects from 1997-2008 was less than 1.

Despite the model identifying similar important landscape variables as other studies, the identification of a land cover class is not necessarily the best predictor of habitat quality (Irwin 1994). Bobcats occur in a wide variety of habitats thus occupancy is often not a function of habitat type, but of habitat structure (Anderson and Lovallo 2003). Habitat structure such as understory density or abundance of rocky outcroppings may influence factors pertinent to bobcat distribution such as prey availability, hunting and feeding methods, and snow avoidance behavior (McCord 1974). Unfortunately, habitat structure is difficult to measure on a landscape scale with GIS and therefore hard to incorporate in large-scale predictive models. Advances in remote sensing technology that permit the estimation of stand age and density may allow the inclusion of some of these variables in future landscape models (Sivanpillai et al. 2006).

Knick and Rotenberry (1998) recommended if employing a distance statistic that (i) animals should be distributed optimally, (ii) the landscape should be well sampled to determine the mean habitat vector, and (iii) distributions of the habitat variables should not change. Given these recommendations, the results from my model should be interpreted with caution. First, bobcat locations used to build the model may not have been distributed optimally. All radio-located bobcats came from a harvested population. Pressure from hunting may influence bobcat movement and distribution (Rolley 1985); thus, bobcats may be found mostly in areas that are difficult to access by foot or vehicle to avoid predation by humans and not in areas that are otherwise optimal. Second, the small sample size of bobcats used to generate the model may not reflect a well sampled population. While bobcats core areas were estimated from three different study areas, all study sites were geographically limited to the harvest zone of the northern forests. In addition, measurement error associated with estimating radio-locations (Visscher 2006), in particular the locations from the CNF and NNF that were obtained with bi-angulation only, could further limit the accuracy of a small sample size. Mean vectors were calculated based on core areas, rather than individual bobcat locations to try and reduce measurement error, however, telemetry imprecision would still impact the accuracy. Third, variation existed in the habitat variables across the model study area. The landscape of northern Wisconsin is characterized by extensive coniferous and hardwood forest cover and a topography that is flat to moderately rolling. In contrast, the landscape of central and southern Wisconsin is characterized by a matrix of hardwood forests, prairies, and agricultural cover. Topography ranges from flat in the central region to rugged hills with steep bluffs in the southwest region (Curtis 1959). Overall, it may be most appropriate to develop a separate habitat model for the southern, non-harvest region of Wisconsin.

The performance of this model may also be influenced by the use of land cover data from two different time periods. The overall classification accuracy of the 1992 land cover data was 86% while the overall classification accuracy of the 2001 land cover data was 91.2%. The difference in accuracy was illustrated by the urban cover class; the land cover data from 1992 and 2001 were developed at the same scale (30mx30m), however roadways were not detected and classified in the earlier dataset whereas roadways were classified as 'urban' cover in the more recent dataset. This difference not only affected the variable that measured the percentage of urban land cover, it also affected the variable that described the amount of edge in the landscape.

Understanding distribution and abundance is essential for a harvested species (Lancia 1994). Bobcats in particular are sensitive to overharvest due to their low reproductive rate and low population density (Knick 1990). Wildlife managers need to balance the needs of constituents with the requirements of a species in order to provide sound management strategies that result in sustainable populations. When developed appropriately and evaluated thoroughly, predictive habitat models can be a valuable tool for identifying suitable habitat at a landscape scale and aiding wildlife managers. It is important to remember, however, that habitat suitability is not synonymous with habitat occupancy.

MANAGEMENT IMPLICATIONS

The Penrose distance model identified the majority of potentially suitable bobcat habitat as occurring in the harvest zone of northern Wisconsin in addition to isolated areas in central and southern Wisconsin. The results from sighting data and scat surveys suggest their potential use in future survey efforts in areas where winter tracking and a harvest are not feasible. The performance of the model suggests a need for further research in the central and southern regions of the state.

Specifically, research should be conducted that examines bobcat-habitat relationships with radio-collared bobcats outside of the current harvest zone before any changes to the current harvest regime are implemented. Future modeling efforts should attempt to incorporate more abiotic landscape variables and take advantage of advances in remote sensing technology.

ACKNOWLEDGEMENTS

I thank E. Cooney, M. Jones, K. Winford, E. Michel, A. Oldakowski, Wisconsin Trappers Association (WTA) volunteers, and Tango the detection dog for field assistance. Funding for this project was provided by the Wisconsin Department of Natural Resources, Citizen-based Monitoring Partnership Program of the WDNR, WTA, Wisconsin Bear Hunters Association, Safari Club International, the Jack Massopust Memorial Scholarship and the University of Wisconsin-Stevens Point. B. Sloss and R. Franckowiak of the Wisconsin Cooperative Fishery Unit and N. Wetzel at UWSP provided invaluable project support. J. Olson, R. Rolley, and B. Dhuey provided advice and WDNR data. I thank M. Lovallo and J. Gilbert for bobcat radio-location data.

LITERATURE CITED

Aebishner, N. J., P. A. Robertson, and R. E. Kenward. 1993. Compositional analysis of habitat use from animal radio-tracking data. Ecology 74:1313-1325.

Agee, J. K., S. C. F. Stitt, M. Nyquist, and R. Root. 1989. A geographical analysis of historical grizzly bear sightings in the North Cascades. Photogrammetric Engineering and Remote Sensing 55:1637-1642.

Anderson, E.M., and M. J. Lovallo. 2003. Bobcat and lynx. Pages 758-782 *in* Feldhammer, G.A., Thompson, B.C., Chapman, J.A. (Eds.), Wild Mammals of North America: Biology, Management, and Conservation, second edition. John Hopkins Press, Baltimore, MA, USA.

Benson, D. A., I. Karsh-Mizrachi, D. J. Lipman, J. Ostell, and D. L. Wheeler. 2005. GenBank. Nucleic Acid Research 33:D34-D38.

Bluett, R. 1984. The bobcat. Wisconsin department of natural resources. Bureau of wildlife management.

Clark, J. D., J. E. Dunn, and K. G. Smith. 1993. A multivariate model of female black bear habitat use for a geographic information system. Journal of Wildlife Management 57:519-526.

Constable, J. L., M. V. Ashley, J. Goodall, and A. E. Pusey. 2001. Noninvasive paternity assignment in Gombe chimpanzees. Molecular Ecology 10:1279–1300

Curtis, J. T. 1959. The vegetation of Wisconsin. University of Wisconsin Press, Madison, USA.

Dhuey, B. 2008. Winter track counts, 1977 - 2008. *In* The Wisconsin Wildlife Surveys Report. Document on file at the Wisconsin Department of Natural Resources, Bureau of Research, Monona, WI

Dhuey, B., and J. Olson. 2007. Bobcat harvest, 2007. *In* The Wisconsin Wildlife Surveys Report. August 2007. Document on file at the Wisconsin Department of Natural Resources, Bureau of Research, Monona, WI.

Drummond, A. J., B. Ashton, M. Cheung, J. Heled, M. Kearse, R. Moir, S. Stones-Havas, T. Thierer, and A. Wilson. 2007. Geneious v3.0, Available from http://www.geneious.com/

Fernandez, N., M. Delibes, and F. Palomares. 2006. Landscape evaluation in conservation: molecular sampling and habitat modeling for the Iberian lynx. Ecological Applications 16(3):1037-1049.

Foran, D. R., K. R. Crooks, and S. C. Minta. 1997. Species identification from scat: and unambiguous genetic method. Wildlife Society Bulletin 25:835-839.

Fuller, T. K., W. E. Berg, and D. W. Kuehn. 1985. Bobcat home range size and daytime cover-type use in north-central Minnesota. Journal of Wildlife Management 66:568-571.

Gilbert, J. 2003. Impacts of reestablished fishers on bobcat populations in Wisconsin. Dissertation, University of Madison, Wisconsin

Guisan, A., and N. E. Zimmermann. 2000. Predictive habitat distribution models in ecology. Ecological Modelling 135:147-186.

Hellgren, E., S. L. Bales, M. S. Gregory, D. M. Leslie, Jr., and J. D. Clark. 2007. Testing a Mahalanobis distance model of black bear habitat use in the Ouaachita Mountains of Oklahoma. Journal of Wildlife Management 71:924-928.

Hoezel, A. R., and A. Green. 1992. Analysis of population-level variation by sequencing PCR-amplified DNA. Pages 159-187 *in* A. R. Hoelzel, editor. Molecular genetic analysis of populations: a practical approach. IRL Press, Oxford, UK.

Homer, C., C. Huang, L. Yang, B. Wylie, and M. Coan, 2004. Development of a 2001 national land cover database for the United States. Photogrammetric Engineering and Remote Sensing Vol.70, No.7, pp 829-840.

Hunsaker, C. T., M. F. Goodchild, M. A. Friedl, and T. J. Case. 2001. Spatial uncertainty in ecology: implications for remote sensing and GIS applications. Springer, New York, New York, USA.

Irwin, L. L. 1994. A process for improving wildlife habitat models for assessing forest ecosystem health. The Journal of Sustainable Forestry 2:293-306.

Johnson W. E., Culver M., Iriarte J.A., Eizirik E., Seymour K., and O'Brien S. J. 1998. Tracking the elusive Andean mountain cat (*Oreailurus jacobita*) from mitochondrial DNA.. Journal of Heredity 89:227-232.

Johnson, C. J., S. E. Nielsen, E. H. Merrill, T. L. McDonald, and M. S. Boyce. 2006. Resource selection functions based on use-availability data: theoretical motivation and evaluation methods. Journal of Wildlife Management 70:347-357.

Kaukinen, D., A. Carr, R. Rempel, P. Elkie, R. Kushneriuk,J. Elliott, and J. Robinson. 2007. Patch Analyst for ArcGIS. Ontario Ministry of Natural Resources, Thunder Bay, Ontario, Canada.

Keating, K. A., and S. Cherry. 2004. Use and interpretation of logistic regression in habitat-selection studies. Journal of Wildlife Management 68:774-789.

Knick, S. T. 1990. Ecology of bobcats relative to exploitation and a prey decline in southeastern Idaho. Wildlife Monographs 108:3-42.

Knick, S. T., and D. L. Rotenbury. 1998. Limitations to mapping habitat use areas in changing landscapes using the Mahalanobis distance statistic. Journal of Agricultural, Biological, and Environmental Statistics 3:311-322.

Koehler, S. A. 2006. Habitat selection and demography of bobcats (*Lynx rufus*) in Iowa. Thesis, Iowa State University, Ames, Iowa.

Lancia, R. A., J. D. Nichols, and K. H. Pollock. 1994. Estimating the number of animals in wildlife populations. Pages 215-253 *in* T. A. Bookhout, ed. Research and management techniques for wildlife and habitats. Fifth edition. The Wildlife Society, Bethesda, Maryland, USA.

Litvaitis, J. A., J. A. Sherburne, and J. A. Bissonette. 1986. Bobcat habitat use and home range size in relation to prey density. Journal of Wildlife Management 50:110-117.

Lovallo, M. J. 1993. Bobcat behavior and home range use in northwestern Wisconsin: in reference to censusing populations. Thesis, University of Wisconsin, Stevens Point, Wisconsin.

Lovallo, M. J. 1999. Multivariate models of bobcat habitat selection for Pennsylvania landscapes. Dissertation, The Pennsylvania State University, University Park, Pennsylvania, USA.

Lovallo, M. J., and E. M. Anderson. 1996. Bobcat (*Lynx rufus*) home range size and habitat use in northwest Wisconsin. American Midland Naturalist 135:241-252.

Lovallo, M. J., G. L. Storm, D. S. Klute, and W. M. Tzilkowski. 2001. Multivariate models of bobcat habitat selection for Pennsylvania landscapes. Pages 4-17 *in* A.Woolf, C. K. Nielsen, and R. D. Bluett, editors. Proceedings of a symposium on current bobcat research and implications for management. The Wildlife Society 2000 Conference, Nashville, Tennessee, USA

Manly, B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. Second edition. Kluwer Press, New York, New York, USA.

Manly, B. F. J. 2005. Multivariate statistical methods: a primer. Third edition. Chapman and Hall/CRC Press, Boca Raton, Florida, USA.

McCord, C. M. 1974. Selection of winter habitat by bobcats (*Lynx rufus*) on the Quabbin Reservation, Massachusetts. Journal of Mammalogy 55:428-437.

McGarigal, K., S. A. Cushman, M. C. Neel, and E. Ene. 2002. FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following web site: www.umass.edu/landeco/research/fragstats/fragstats.html

Mills, L. S., K. L. Pilgrim, M. K. Schwartz, and K. McKelvey. 2000. Identifying lynx and other North American felids based on MtDNA analysis. Conservation Genetics 1:285-288.

Millspaugh, J. J. and J. M. Marzluff. , editors. 2001. Radio tracking and animal populations. Academic, San Diego, California, USA.

Mladenoff, D. J., T. Sickley, R. G. Haight, and A. P Wydeven. 1995. A regional landscape analysis and prediction of favorable gray wolf habitat in the northern Great Lakes region. Conservation Biology 9:279-294.

Nielsen, C. K., and A. Woolf. 2002. Habitat-relative abundance relationship for bobcats in southern Illinois. Wildlife Society Bulletin 30:222-230.

Neu, C. W., C. R. Byers, and J. M. Peek. 1974. A technique for analysis of utilization-availability data. Journal of Wildlife Management 38:541-545.

Oka, T., and O. Takenaka. 2001. Wild gibbons' parentage tested by noninvasive DNA sampling and PCR-amplified polymorphic microsatellites. Primates 42:67–73.

Palma, L., P. Beha, and M. Rodrigues. 1999. The use of sighting data to analyze Iberian lynx habitat and distribution. Journal of Applied Ecology 36:812-824.

Pearce, J. L., and M. S. Boyce. 2006. Modelling distribution and abundance with presence-only data. Journal of Applied Ecology 43:405-412.

Pruess, T. S. and T. M. Gehring. 2007. Landscape analysis of bobcat habitat in the northern lower peninsula of Michigan. Journal of Wildlife Management 71:2699-2706.

Rodgers, A.R., A.P. Carr, H.L. Beyer, L. Smith, and J.G. Kie. 2007. HRT: Home Range Tools for ArcGIS. Version 1.1. Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario, Canada.

Rolley, R. E. 1985. Dynamics of a harvested bobcat population in Oklahoma. Journal of Wildlife Management 49:283-292.

Rolley, R. E., B. E. Kohn, and J. F. Olson. 2001. Evolution of Wisconsin's bobcat harvest management program. Pages 61-66 *in* A.Woolf, C. K. Nielsen, and R. D. Bluett, editors. Proceedings of a symposium on current bobcat research and implications for management. The Wildlife Society 2000 Conference, Nashville, Tennessee, USA.

Samuel, M. D., D. J. Pierce, and E. O. Garton. 1985. Identifying areas of concentrated use within the home range. Journal of Animal Ecology 54:711-719.

Seaman, D. E. and R. A. Powell. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology 77:2075-2085.

Seaman, D. E., J. J. Millspaugh, B. J. Kernohan, G. C. Brundige, K. J. Raedeke, and R. A. Gitzen. 1999. Effects of sample size on kernel home range estimates. Journal of Wildlife Management 63:739-747.

Stoms, D. M., F. W. Davis, C. P. Cogan, M. O. Painho, B. W. Duncan, J. Scepan, and J. M. Scott. 1993. Geographic analysis of California condor sighting data. Conservation Biology 7:148-159.

Sivanpillai, R., C. T. Smith, R. Srinivasan, M. G. Messina, and X. B. Wu. 2006. Estimation of managed loblolly pine stand age and density with Landsat ETM+ data. Forest Ecology and Management 223:247-254.

SPSS. 2007. SPSS Version16.0.1 for Windows. SPSS Inc., Chicago, Illinois, USA

Visscher, D. R. 2006. GPS measurement error and resource selection functions in a fragmented landscape. Ecography 29:458-464.

Wisconsin Department of Natural Resources [WDNR]. 2005. Bureau of Enterprise Information and Technology & Applications. Wisconsin DNR 24K Hydrography. <http://dnr.wi.gov/maps/gis/datahydro.html>. Accessed 22 Apr 2007.

Woolf, A., C. K. Nielsen, T. Weber, T. J. Gibbs-Kieninger. 2002. Statewide modeling of bobcat, *Lynx rufus*, habitat in Illinois, USA. Biological Conservation 104:191-198.

Zar, J. H. 1999. Biostatistical analysis. Fourth edition. Prentice-Hall, Upper Saddle River, New Jersey, USA

CHAPTER 2:

A COMPARISON OF SURVEY METHODS FOR BOBCATS (*LYNX RUFUS*) IN WISCONSIN

ABSTRACT

Bobcat (*Lynx rufus*) populations in northern climates are often monitored with winter track counts, however variable tracking conditions coupled with the low density and elusive nature of bobcats result in low detection rates. I compared detection rates, cost, and field time required of winter track counts with new survey methods including hair-snares and a detection dog trained to locate bobcat scat. The detector dog detected four times the number of detections compared to winter track counts. The hair snare method produced the least number of detections. The detection dog was the most expensive method per transect while the winter track-counts were the least expensive. Despite being the most expensive method, the cost per detection of the detector dog was comparable to the other methods due to its high detection rate. All three survey methods required comparable field times. The detector dog method may allow wildlife managers to better understand bobcat distribution and population trends where winter track counts are not feasible.

INTRODUCTION

Sustainable management of harvested populations requires accurate estimators of abundance (Lancia et al. 1994). Bobcats, in particular, are sensitive to over harvest (Knick 1990) leading bobcat managers throughout the U.S to identify the top research need as the development of a reliable survey method (Bluett et al. 2001). Winter track-count surveys are used in Wisconsin to monitor bobcat populations despite low rates of detection due to low density, large home ranges, and elusive habits (Diefenbach et al. 1994, Rolley 1987). The current indices derived from winter track counts are prone to several limitations including error in track identification and variable tracking conditions (Aubry and Lewis 2003). Due to the varying snow conditions across space and time, the use of snow tracking at a regional or national scale is problematic due to difficulties in achieving equal sampling efforts across locations (Squires et al. 2004). For example, from 1997-2007, an average of only 64% of established winter track routes throughout northern and central Wisconsin were surveyed annually.

Track count surveys can be successful in detecting population trends in felids, but are most useful when coupled with other survey methods including invasive techniques such as radio-collaring and hunter kill or non-invasive techniques such as scent stations (Van Dyke et al. 1986, Choate et al. 2006). Scent stations are used in Minnesota, but have been rejected as an alternative census method in Wisconsin because of low rates of detection coupled with increased field costs compared to winter track counts (Lovallo 1993, J. Olson, Wisconsin Department of Natural Resources, personal communication). Hair snares have been successfully used for monitoring lynx (*Lynx canadensis*) (McDaniel et al. 2000) and ocelot (*Leopardus pardalis*) (Shinn 2002, Weaver et al. 2005), but has had inconsistent results with bobcats (Harrison 2006, Long et al. 2007b, Ruell and Crooks 2007). Hair snares rely on a scent lure to attract the bobcat to the snare and entice the bobcat to rub on the snare. Detector dogs have been used in conservation research to locate scats from target carnivore species to determine species presence/absence and distribution (Smith et al. 2001, Smith et al. 2003, Wasser et al. 2004, Long et al. 2007a). In addition, Kerley and Salkina (2007) documented the potential of detector dogs to estimate felid population size with mark-recapture methods. Detector dogs trained to locate bobcat scat have had higher rates of encounter when compared to other methods (Harrison 2006, Long et al. 2007b). Also, while the success rate of species identification with DNA analysis is comparable between hair and scat samples, scat samples are recommended if individual identification is needed (Ruell and Crooks 2007). There has been no comparative study between detection dogs and winter track counts.

My objective was to compare the detection rates, cost, and time required for winter track counts, hair snares, and detector dog to determine the most efficient technique to conduct bobcat presence/absence surveys with the potential to index population size and estimate abundance. The first part of the study evaluated independent samples of the three survey methods. The second part of the study compared a subsample of winter track routes, hair snare transects and detector dog transects.

STUDY AREA

Study sites were primarily located in the northern, central, and southwest regions of Wisconsin. Forests cover approximately 80% of the northern region. Northern forests are typically characterized by the presence of conifers such as white cedar (*Thuja occidentalis*), black spruce (*Picea mariana*), and balsam fir (*Abies balsamea*) on lowland sites while jack pine (*Pinus banksiana*), red pine (*P. resinosa*), and white pine (*P. strobus*) dominate upland sites. A large hardwood component is also present including black ash (*Fraxinus niger*) and alder (*Alnus spp*.) on lowland sites while the uplands support mature aspen (*Populus tremuloides*), red maple (*Acer rubrum*), and white birch (*Betula papyrifera*). Topography was flat to moderately rolling and underlain with poorly drained ground moraine. Central Wisconsin is composed of approximately 40% forest cover. The forested portion is mostly oak (*Quercus spp.*)dominated forest, followed by aspen (*Populus spp.*) and pines (*Pinus spp*.). A minor portion is maple (*Acer spp*.)-basswood (*Tilia americana*) forest and lowland hardwoods. The non-forested region is mostly in agriculture and grassland. Southwest Wisconsin consists of a mixture of forest (40%), agriculture, and grassland with some wetlands in the river valleys. The primary forest cover (51%) is oak-hickory (*Carya spp*.). Maple-basswood forests (28%), dominated by sugar maple, basswood and red maple, are common in areas that were not subjected to repeated pre-settlement wildfires. Bottomland hardwoods (10%) are common in the valley bottoms of major rivers and are dominated by silver maple (*A. saccharinum*), ashes (*Fraxinus* *spp*.), elms (*Ulmus spp*.), cottonwood (*P. deltoids),* and red maple. Topography ranges from flat in the central region to rugged hills with steep bluffs in the southwest region (Curtis 1959).

METHODS

Survey Methods

Winter track routes – Forty 16 km long winter track routes were established in northern Wisconsin by the WDNR in 1977 with 1-2 transects per county separated by at least 16 km. An additional 10 routes were established in 1998 in central Wisconsin. Routes were generally located in areas having good habitat of mixed aspen, alder, and conifers while large areas of unbroken pine and hardwoods were avoided. Roads that were least likely to be plowed following a storm and with minimal traffic were chosen for transects. The number of observed bobcat tracks was documented annually along routes by wildlife managers and researchers on the first day after a snowfall, allowing one night for track registry. Number of bobcat tracks per transect were recorded; if it was obvious that an animal ran along the road, its tracks were only counted once (Dhuey 2008). Due to annually fluctuating tracking conditions, I utilized track data from the winters of 1997-2007 in addition to data from the winter of 2007 only.

Hair snare survey– Forty-eight hair snare transects were established from Jul-Aug, 2008 in northern, central, and southwestern Wisconsin. An additional 41 transects were established by citizen scientists in northern and central Wisconsin. Each transect was 4.5 km long and comprised of 10 hair snares spaced 500 m apart along secondary roads and trails. For efficiency, I established groups of 2-4 transects within the same geographical location (Fig. 1). Thirty six of the 48 transects were established on or near pre-existing 16km long winter track routes. Two hair snare transects overlapped the beginning and end 4.5km long portions of a winter track route (i.e., overlapping a 9 km

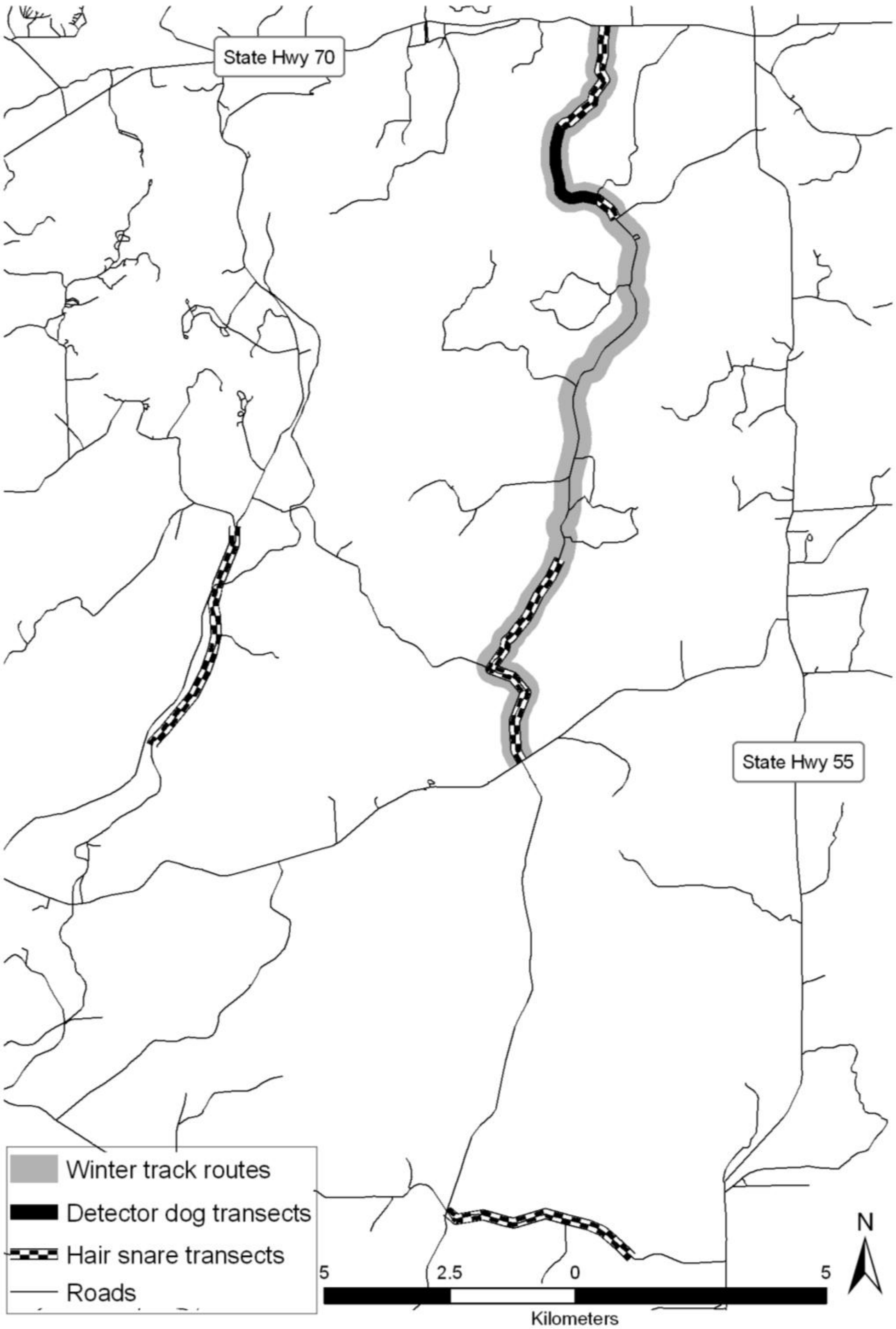

Figure 1. Example of study site for comparing bobcat survey methods including 16km long winter track routes, 4.5 km long hair-snare transects, and a 2km long transect that was surveyed by a detector dog trained to locate bobcat scat. Surveys occurred in Jul – Aug 2008 in Forest County, Wisconsin, USA

or 56% portion of winter track routes). One to two additional hair snare transects were established between 5-16 km apart from the winter track route. A minimum distance of 5 km between transects was instituted to reduce detecting the same individual bobcat on multiple transects. No winter track routes existed in southwest Wisconsin; I established routes (n=12) in this region based on availability of public and private land where I could obtain permission to erect hair snares. Hair snares were erected 500 m apart on 4.5 km long transects along secondary roads and trails. Snares were placed up to 10 m from the road in public use areas. Hair snares consisted of a shelf bracket mounted to a tree at a height of 0.3 m above the ground with a 30.5 x 12.7-cm piece of landscape edging fastened to the bracket arm perpendicular to the tree (Fig. 2). A 20.3 x 12.7-cm glue board (Catchmaster, AP&G Co., Brooklyn, New York) was secured to the underside of the edging with mounting tape and baited with 2 ml of Super All Call (Lenon's Animal Lures, Gulliver, Mich.). Also, 2 ml of Carmen's Canine Call (R. Carmen, New Milford, PA) was deposited on a branch within 5 m of the snare as a call lure.

Figure 2 .Hair snare station attached to tree with glue board baited with scent lure, CD hung from branch, and sign.

Glue was chosen for this study because of: 1) large quantities of hair samples recovered from glue based snares during trials with captive cougars (E. Anderson, University of Wisconsin- Stevens Point, personal communication) and 2) the ease with which citizen volunteers could re-cover sampled glue boards with the original release paper to minimize contamination and facilitate delivery by mail. Lures were chosen based on results from scent trials with captive bobcats prior to the field season (Chapter 3). For a visual attractant I hung a compact disc within 3 m of the hair snare that hung approximately 1 m above ground

Hair snares were left in place for 4 weeks and checked and re-baited after 2 weeks. Glue boards with deposited hairs were collected and replaced with a new glue board. Collected glue boards were covered with their original release paper, placed in manila envelopes and stored in a cool dry place until genetic analysis..

Genetic analysis of hair samples was performed at the Molecular Conservation Genetics Lab of the Wisconsin Cooperative Fishery Research Unit (UW-SP, Stevens Point, WI). DNA was extracted from samples using the Qiagen DNeasy® Blood and Tissue Kit (Qiagen Inc., Valencia, CA). When possible, a minimum of 15 hairs and no more than 25 hairs were used as source tissue and the manufacturer's recommended protocol was followed except five separate final elutions were performed with 50 μLof TLE to ensure adequate DNA quantity. Following extraction, all extractions were checked for DNA quality (i.e., molecular weight) by electrophoresing an aliquot of DNA in a 0.7% agarose gel with ethidium bromide. The gel was visualized using UV light and the molecular weight of each sample compared to a known standard (Hyperladder™ I, Bioline, Inc., Randolph, MA). DNA quantity was determined using a Nanodrop® ND-1000 spectrophotometer (Nanodrop Technologies, Wilmington, DE). Previous studies of felid species identity have shown the DNA sequence of the universal portion of the mitochondrial 16S rRNA gene provides for diagnostic species identification (Foran et al. 1997; Johnson et al. 1998; Mills et al. 2000). We used the 16S rRNA primers (16S-1F and 16S-4R) of Hoelzel and Green (1992) to amplify an approximately 376 base pair portion of the 16S rRNA gene for species identification following the reaction conditions of Johnson et al. (1998). Amplicons were checked for single bands using a 2% agarose-TBE gel with ethidium bromide and visualized on a UV light. All successful amplifications were purified using Millipore MultiScreen® $PCR_{\mu96}$ MultiScreen filter plates (Millipore Corp., Billerica, MA, USA) and the manufacturer's recommended protocol. DNA sequencing was performed using ABI BigDye® v3.1 (Applied Biosystems, Inc., Foster City, CA, USA) and one of the PCR primers, cleaned of unincorpated dideoxynucleotides using Millipore Montage Seq96 Sequencing Reaction cleanup kit (Millipore, Inc.), and sequenced on an ABI 3730 DNA Analyzer (Applied Biosystems). Sequence data was proofed in Geneious (Drummond et al. 2007), and compared to known species sequences in GenBank (Benson et al. 2005).

Detection dog – I hired a detector-dog-handler team (Kristin Winford, Ashland, Wisconsin) that surveyed for bobcat scat along a 2 km portion of the 4.5km long hair snare transects (n = 16) and a 2 km portion of the 16 km long winter track routes (n=10) (Fig. 1). Detection of a target sample is motivated by the dog's anticipated reward of a play object. The detector dog was trained for 20 days prior to field work with techniques similar to those used to train dogs to detect narcotics, explosives, and humans (Smith et al. 2003, Wasser et al. 2004). At least 200 scats from harvested and captive bobcats (representing numerous individuals and a wide range of food items) was used to train the detection dog. This protocol ensured that the dog was trained on the species' scent rather than that of an individual animal or specific food items. Scats were frozen upon collection but were thawed and allowed to age up to 2 weeks prior to training. The probability of detection and the maximum distance of detection from the transect was calculated in a double blind trial transect. Scats were placed along a 2km trial transect in locations unknown to the dog handler and dog. The dog-handler team surveyed each transect for bobcat scat for 2-4 hours between dawn and midday. When the dog located a potential bobcat scat, the dog alerted the handler by sitting next to the scat and looking at the handler. Since it was not possible to immediately confirm whether scats found on the transect were bobcat, the dog was acknowledged for finding a scat, but not rewarded with play. The handler would acknowledge the dog by walking up to him, squatting down to his level, facing the same direction he was facing, and petting him from neck to flank on the opposite side of the body. The handler reinforced the trained 'alert' behavior for the dog on the correct target (bobcat scat) by hiding known bobcat scat before and after every transect, and in the middle of the transect for approximately 50% of the transects. When the known bobcat scat was found, the dog was rewarded by getting to play with a ball. Scats were collected up to 30 m away from the transect line and either immediately frozen if possible (Constable et al. 2001), or deposited in 95% ethanol (Oka and Takenaka 2001). To minimize the probability of committing a false negative error by failing to detect a bobcat that was indeed present, the handler also collected scats in which the detector dog did not alert, but showed a high interest (e.g., stood next to the scat, but did not sit). Scat locations were recorded on a1:24,000-scale aerial photo of the transect. Scats were processed at the Molecular Conservation Genetics Lab of the Wisconsin Cooperative Fishery Research Unit (UW-SP, Stevens Point, WI) for species identification. DNA extractions were performed in a controlled environment using the QIAamp® DNA stool mini kit (QIAgen, Inc., Valencia, CA) and the manufacturer's 'Protocol for Isolation of DNA from Stool for Human DNA Analysis'. Each scat sample was extracted five times with samples from across the length of the scat. All extractions were performed under conditions aimed to minimize the potential for contamination among samples. As such, only a single fecal sample was allowed out of storage at a given time, disposable, scalpel blades were used to scrape the recommended amount of fecal material from the scat and a new blade was used for each scat, filtered tips were employed for all liquid handling, and all surfaces were wiped down between samples using a 5% bleach solution and lab bench paper was replaced for each new scat sample. 16S rRNA amplification was as described previously for hair samples. When multiple products were observed on the 2% agarose check gel, gel-purification of the target product (~376 bp) was performed in a 2% agarose TAE gel with the Eppendorf PerfectPrep® Gel Cleanup kit (Eppendorf North America, Westbury, NY, USA) following the manufacturer's recommended protocol.

Comparison of methods- I surveyed 10 transects for the comparison of winter tracks, hair snares, and detector dog. For each method, I determined (i) the total number of bobcat detections, (i) the mean number of bobcat detections per transect, (iii) the percentage of transects with detections, (iv) the cost for each method, (v) the cost per detection, and (v) the number of days required. I compared the number of transects in which a bobcat was detected between the track-count and detector dog method with the McNemar's test of symmetry (Zar 1999). Also, I conducted nonparametric Spearman rank correlations between the number of tracks detected and the number of scats detected among transects (Zar 1999).

RESULTS

Winter track routes only – In 2007, 29 of 50 (58%) winter track routes were conducted. Forty-five percent of routes had detections while the mean number of detections per route was 0.62 and a total of 18 bobcats were detected (Table 1). From 1997-2007, an annual average of 32 of 50 (64%) of winter track routes were conducted. Each year, an average of 24 (SE=3.78) bobcats were detected while the mean number of detections per route was 0.76 (SE=0.07) and 41% (SE=0.03) of routes had detections.

Table 1. Comparison of detection rate for bobcat surveys with a dectector dog, hair snares, and winter track-counts on transects throughout Wisconin during Jul-Aug 2008 (n=number of transects.

Sample	Method	No. of bobcat detections[a]	Mean no. of detections/transect	Percentage of transects with detections (%)
All	Tracks (n=50)	18[b]/24[c]	0.62[b]/0.76[c]	45%[b]/41%[c]
	Hair-Snares (n=48)	2	0.04	2%
	Detector Dog (n=16)	11/(79%)[d]; 3/(12%)[e]	0.875	38%
Comparison	Track (n=10)	3[d]/3.9[e]	0.6[d]/0.87[e]	40%[d]/43%[e]
	Hair-Snare (n=10)	0	0	0%
	Detector Dog (n=10)	10/(77%)[f]; 2/(22%)[g]	1.2	40%

[a] Percentages of total numbers of scats tested are in parenthesis
[b] Track-count data from n=32 routes during the winter of 2007/2008
[c] Track-count data from n= 29 routes during the winters of 1997-2007
[d] Track-count data from n=5 routes during the winter of 2007/2008
[e] Track-count data from n= 4.8 routes during the winters of 1997-2007
[f] Scats that eliceted an alert response from the detector dog
[g] Scats that eliceted an interest response from the detector dog

Hair snares only - I collected 201 hair samples from 480 hair snares over 13,440 hair snare nights. I detected hair samples of 2 bobcats, 56 non-specific rodents, 31 flying squirrels (*Glaucomys spp*.), 18 humans, 16 opossums (*Didelphis virginiana*) , 12 bears (*Ursus americanus),* 10 as either wolf or domestic dog (*Canis lupus* or *Canis lupus familiaris),* 8 raccoons (*Procyon lotor*), 8 chipmunks (*Tamias striatus*), 1 red squirrel (*Tamiasciurus hudsonicus*), and 1 mustelid. Thirty-eight samples could not be identified by DNA analysis because of either insufficient or low quality DNA. Bobcats were detected on 2% of hair snare transects and 0.004% of snares (Table 1). Samples collected by citizen volunteers were not included in analysis due to deviances from protocol in hair collection methods that led to high probabilities of contamination.

Detection dog only – The detector dog identified 100% of the bobcats scats from probability of detection trial transect. Scats were detected a maximum of 30 m from the transect. No non-target scats were identified by the detector dog during the trial. The detector dog identified a total of 14 bobcat scats from 38% of transects (Table 1). The detector dog alerted on 14 scats and found interest in another 25. Of the 14 "alert" scats, DNA analysis confirmed 11 as bobcat, 1 as coyote, and failed for 2. Of the 25 "interest" scats, DNA analysis confirmed 3 as bobcat, 6 as red fox (*Vulpes vulpes*), 5 as either wolf or domestic dog, 3 as coyote (*Canis latrans*), 1 as domestic cat (*Felis catus*), 1 as cottontail rabbit (*Sylvilagus floridanus)*, 1 as snake, 1 as white-tailed deer (*Odocoileus virginianus*), and failed for 4 because of either insufficient or low quality DNA.

Track-counts/hair- snares/detector dog- During the winter of 2007, 5 of the 10 winter track routes were surveyed. A total of 3 bobcats were detected from 2 routes, while the mean number of detections per surveyed route was 0.60 (SE = 0.40). From 1997-2007, an average of 4.81 (SE = 0.54) of the 10 routes were surveyed annually. Each year, an average of 3.91 bobcats (SE = 1.07) were detected while the mean number of detections per surveyed route was 0.87 (SE=0.21) and 43% (SE=7.96) of surveyed routes had detections. The detector dog identified a total of 12 bobcat scat on 4 of 10 (40%) transects (Table 1). I collected 37 hair samples from 100 hair snares over 2,800 hair snare nights on the 10 comparison transects. Of the 37 hair samples, DNA analysis confirmed zero as bobcat, 13 as non-specific rodent, 7 as flying squirrel, 6 as dog, 4 as human, 2 as bear, 1 as chipmunk, 1 as raccoon, and failed for 3. The detector dog alerted on 13 scats and found interest in an additional 9. Of the 13 "alert" scats, DNA analysis confirmed 10 as bobcat, 1 as coyote, and failed for 2. Of the 9 "interest" scat, DNA analysis confirmed 2 as bobcat, 3 as either wolf or domestic dog, 3 as coyote, and failed for 1. There was no significant difference in the number of transects in which a bobcat was detected between the track-count and detector dog method ($p = 1$). The number of tracks detected was not correlated to the number of bobcat scats detected across transects (Spearmans rho = 0.17, $p = 0.64$).

Cost and time comparison – The winter track-counts cost $180-$260 per transect (Table 2). This included (i) labor costs of $160 per transect, and (ii) travel costs between $28-$108 per transect. Labor costs were estimated based on 1 WDNR biologist conducting 1 transect per day at a rate of $20

Table 2. Comparison of cost and field time required for bobcat surveys with a detector dog, hair-snares, and winter-track counts on transects in northern and central Wisconsin (n=10 transects)

Method	Cost per transect ($) Materials	Lab[a]	Labor	Travel[b]	Total Cost/Transect	Cost/Detection[c]	Field time required (days)
Track-Counts	$0	na	$160	$28-$108	$180-$260	$300-$433[d]/$206-$298[e]	5-10
Hair-Snare	$30	$44	$120	$60-$300	$254-494	≥ $254-$494	11
Detector Dog	$0[e]	$143	$150[e]	$104	$397	$330	10

[a]Lab fees were calculated by averaging the total lab cost across the 10 transects. Cost includes processing both bobcat and non-bobcat samples.

[b]Travel includes fuel and per diem. Travel for dog was based on an average of 70 miles/day to complete all 10 transects. Travel for Track was based on the distance from office to route which ranges from 40-200 miles roundtrip.

[c]Calculated by dividing the total cost/transect by the mean no. of detections/transect

[d] Based on track data from n=5 route during the winter of 2007/2008

[e] Based on track data from n=4.8 routes during winters from 1997-2007

[f]Per transect fee paid to dog handler includes pre-season training and materials

per hour (J. Olson, Wisconsin Department of Natural Resources, personal communication). Travel costs were estimated based on round trip distances of 40-200 miles from the closest WDNR office to winter track routes and $8/per diem (J. Olson, personal communication). Based on the mean number of bobcat detections per route during the winter of 2007/2008, the cost per detection was $300-$433 depending on the distance of the route from the office. Based on the mean number of bobcat detections per route from 1997-2007, the cost per detection was $206-$298.

The hair snares cost $254-$494 per transect (Table 2). This included (i) material costs of $30/transect, (ii) travel costs between $60-$300/transect, (iii) labor costs of $120/transect, and (iv) lab costs of $44 based on 3.7 hair samples analyzed per transect at a cost of $12 per sample. The labor and travel portions were incurred during 3 trips: erecting snares, checking snares after 2 weeks, and removing snares after 4 weeks. Hair snare transects for this study were conducted by a graduate student and one field technician based out of Stevens Point, Wisconsin. However, to facilitate the comparison with other methods, rates for labor and travel were calculated based on the assumption that WDNR biologists could have conducted these surveys using the same labor and travel rates associated with winter track-counts. No bobcat hair samples were detected on hair-snare transects thus the projected cost per bobcat detection would be a minimum $254-$494 depending on the distance from a WDNR office.

The detector dog and handler cost $397 per transect (Table 2). This included (i) a base fee of $150 per transect, which included labor, materials, and 20 days of training with bobcat scats, (ii) travel costs of $104/transect including gas reimbursement and per diem (travel and per diem were calculated based on University of Wisconsin 2008 rates), and (iii) lab costs of $143/transect based on 2.2 scats analyzed per transect. DNA analysis of scat cost $13 per extraction, however ≥ 5 DNA samples were

The DNA analysis was performed at the at the Molecular Conservation Genetics Lab at the University of Wisconsin-Stevens Point. Lab fees were charged at cost and rates of the services would most likely be higher at other facilities. Given the mean number of bobcats detected per transect was 1.2, the cost per bobcat detection would be $254-$494 depending on the distance from a WDNR office.

The amount of time required to survey with a detector dog, hair snares, and winter tracks were comparable. The detector dog searched 2 km a day, or 1 transect, however the total distance traveled was 4 km because of the linear transect design. Four hair snare transects could be established in 1 day, plus 1 day for checking, and a final day to remove snares. One additional day was required to prepare materials for four transects. One to two winter track routes could be completed in one day, depending on tracking conditions. The lab component of the hair snare and detector dog methods added significant time to these methods. Lab time required will vary depending on the number of samples and the quality and quantity of the DNA.

DISCUSSION

The detection dog detected the most bobcat samples while the hair snares detected the least. From the comparison transects, detection dogs detected four times as many bobcat samples as winter track-counts and 12 times as many compared to hair-snares. Higher rates of detection with the detection dog were documented despite detection dog transects spatially overlapping only small segments of hair snare transects (2 km of 4.5 km or 44%) and winter track routes (2 km of 16 km, or 13%). However, track-count detection was limited to the immediate roadway whereas the detection dog located scat up to 30m from the road depending on the density of the roadside habitat. Detection dogs can search up to 6 hours a day, or 3-5 km depending on weather (Harrison 2006). While detector dog transects in this study were only 2 km, the dog and handler had to backtrack the 2km to return to the starting point. While at first seen as a disadvantage to the study design in respect to time and stress on the dog, scats were often detected on the return trip. This was ascribed to shifting wind patterns that facilitated the detection of scats that were previously unrecognizable to the detection dog. There was a trade off, therefore, between starting at dawn to take advantage of cooler weather in an attempt to reduce stress to the detection dog, and starting mid-morning to take advantage of increased winds that facilitate the transportation of odors through the environment and allow for easier detection. There was no relationship between the number of scats detected and the number of tracks encountered on the ten comparison transects. In addition, there was no significant difference in the number of transects in which a bobcat was detected between the track-count and detector dog method. The small sample sizes, however, may have precluded the detection of a relationship even if one existed.

An advantage of the detector dog method over the winter track counts was its ability to detect scat samples deposited over a longer period of time. The persistence of scat in the field is influenced by climate, in particular moisture and it is unknown how long scats may be detected by a detection dog (Long et al. 2007a). During the training period for this study, the detection dog was able to identify 2 week-old bobcat scat (K. Winford, personal communication). It is important to remember that the number of scats detected was not synonymous with number of individuals detected. While this study did not discern individual bobcat identity from scats, genotyping could be employed in future studies where estimates of abundance are of interest. Winter track counts were conducted on the first day after the conclusion of a snowfall, allowing only one night for track registry which reduces the probability of counting an individual bobcat multiple times.

Rates of encounter by the detection dog were higher compared to winter track counts despite transects being conducted in July when the rate of encounter may be smaller due to the constricted home ranges of females during kitten-rearing season (Litvaitis et al. 1987, Lovallo and Anderson 1996). Another possible disadvantage associated with the detector dog method was scat removal. Livingston et al. (2005) documented bobcat scat removal rates as high as 50% during the summer season in prairie and forested regions of northeastern Kansas. Sources of removal included coprophagy, burial, and rainstorms. Removal rates were lowest (20%) in winter; however scat surveys conducted during this season in Wisconsin could produce low probabilities of detection as a result of heavy snowfall that could bury scat. Effects of scat removal on surveys using detection dogs may be minimized by conducting studies in the spring when removal rates were lower than summer (30%). Another advantage to conducting surveys in early spring may be an increased probability of detection due to larger home ranges and increased movement associated with the bobcat breeding season (Anderson and Lovallo 2003)

Hair snares did not detect any bobcats on the sub-sample of comparison transects and only two hair samples from all hair snare transects . The lower detection rates compared to the detector dog and winter track count methods may have occurred because, in contrast to passive survey approaches such as detector dogs and winter track counts that do not require an induced response, hair snares require bobcats to alter their normal behavior in three ways: 1) find interest in the scent lure, 2) approach the hair snare, and 3) rub on the hair snare. If rubbed, the hair snare then has to effectively capture the hair. Active survey methods such as the hair-snare are subjective to bobcat behavior including adverse or habituated reactions to the hair collection structure. In addition, the ability of the scent lure to alter bobcat movement may produce a detection where there otherwise would not be and influence inferences about habitat use (Kendall and McKelvey 2007). Based on the poor performance of the hair-snare method using a scent lure combination of beaver castor, catnip oil, and crushed catnip leaves (Harrison 2006) and Weavers Lynx Lure (Long et al. 2007b), I conducted scent trials with captive bobcats prior to the field season with the objective of finding a scent lure that would better induce the rubbing behavior (Chapter 3). Although Lenon's Super All Call was the most effective lure, it elicited only 47% of the sampled cats to rub. Carmen's Canine Call (R. Carmen, New Milford, PA) had the second highest response rates during scent trials and has also been successful for bobcats during other hair snare studies (Ruell and Crooks 2007). Despite this, the results from this study indicated poor performance which may have resulted from using Canine Call as the call lure, instead of using Canine Call directly on the hair snare. Several of the citizen volunteers reported bobcat tracks in the vicinity of hair snares on which there was no hair. In addition to using a call lure, a compact disc was hung nearby as a visual attractant however in dense vegetation the CD was often useless. Poor success may also be attributed to the use of glue as the hair capture device, rather than carpet squares and nails (McDaniel et al. 2000). McDaniel et al. (2000) reported lynx avoided hair snares with a glue substance while Harrison (2006) reported no difference in the quantity of hair removed between hair snares with glue and hair snares with carpet squares and nails. Moisture negatively affected an average of 8% of hair snare stations and up to 50% of stations per transect by decreasing the adhesive strength of the mounting tape used to fasten the glue board to the piece of landscape edging causing the glue board to be removed and either 1) fall to the ground, or 2) become attached to the animal. The use of glue may have also increased the detection rate of non-target species. If an effective scent lure and hair collection device are used, the advantages of hair snares over winter track-counts include: 1) a longer sampling period leading to potentially increased probability of detection and 2) the identification of individual bobcats with DNA analysis.

The detection dog was the most expensive method per transect while the winter track-counts were the least expensive. Despite being the most expensive method, the cost per detection of the detector dog was comparable to the other methods do to its high detection rate. Detection dog rates will vary depending on whether a dog is purchased or leased (Long et al. 2007b). Detection dog costs for this study were approximately half of those reported in Long et al. (2007a) and Harrison (2006) due to a dog/handler team residing in Wisconsin which precluded the costs associated with interstate travel and lodging. Also, while several sites in my study required overnight lodging for the dog/handler team, costs were minimized by their willingness to camp. Even so, the cost of the detection dog per transect doubled that of winter track counts. Both methods required only one visit to a study site, thus travel costs appear to be similar, however, winter track counts were performed by state agency personnel strategically located throughout the state whereas the dog/handler team travelled to all sites from the same point of origin which increased per diem costs due to overnight travel. Hair snares materials were inexpensive, but travel costs were triple that of winter track-counts due to additional trips to re-bait and remove hair-snares. Costs could be reduced in the future by analyzing the cost-effectiveness of long sampling periods that required additional travel costs. Much of the cost associated with the detection dog and hair snares were attributed to lab costs. Lab costs associated with hair-snares could have been reduced by better screening hairs based on morphological structure (Moore 1974). Lab costs associated with the detection dog could have been reduced by reducing the number of "interest" scats analyzed. To do this, it would be important for the detector dog-handler team to receive confirmation through DNA analysis on potential bobcat scat detected in the wild during field trials prior to the field season. Increased lab costs, however, must be considered against the probability of committing a false negative error by failing to detect a bobcat that was indeed present by culling samples.

The field time required for track-counts, detection dog, and hair snares was comparable. My results differ from previous studies where the detector dog required the most field time (Harrison 2006). The time required for hair snares was greater in this study due to a longer sampling period (n=28 days) that required travelling 3 times, rather than 2 to study sites. A shorter sampling period would decrease both time and cost associated with travel, however the 2 bobcat hair samples from this study were detected during the second sampling period. The small sample size prohibited a cost-effective analysis of sampling period length.

The effectiveness of the hair-snare method achieved for lynx and ocelot (McDaniel et al. 2000, Weaver et al. 2005) has not been consistently demonstrated for the bobcat (Harrison 2006, Long et al. 2007, Ruell and Crooks 2007). The evidence from this study does not support the use of hair-snares to detect bobcats. Prior to further hair-snare studies to determine bobcat presence/absence or distribution, research should be conducted in known areas of bobcat abundance to reliably gauge the effectiveness of hair-snares as Weaver et al. (2005) did for ocelots. Pilot studies should take place in similar habitat as the study area of interest. Further research is essential to determine the best scent lure and hair capture device specifically for bobcats.

Winter track counts are an inexpensive method that can provide crude indices of abundance where detectability is consistent. Variable tracking conditions, however, affect the accuracy of this method to not only provide an index of abundance but also describe the distribution of bobcats. The detector dog provides the highest probability of detection in a variety of conditions however it is the most geographically limited in terms of area searched. Unlike winter track-counts, the detector dog could facilitate future research whose goal is to obtain reliable estimates of abundance by learning individual bobcat identity from scats. A survey approach that integrates multiple methods may increase the overall probability of detection, leading to less biased estimates of occurrence and abundance (Campbell et al. 2008).

MANAGEMENT IMPLICATIONS

Detection dogs provided the most effective method for detecting bobcat presence. The field and laboratory costs associated with the detector dog may limit its use to small scale, rather than landscape scale studies. Small scale mark-recapture studies could be implemented by surveying an area multiple times with a detector dog and identifying bobcat scat to individual with genotyping. A mark-recapture study using detection dogs would be less invasive and more feasible than traditional capture-recapture methods that are often cost-prohibitive with large carnivores. Future research should further examine the relationship between detector dogs and other survey methods, especially in areas where winter track counts are prohibitive.

ACKNOWLEDGMENTS

I thank E. Cooney, M. Jones , K. Winford, E. Michel, A. Oldakowski, Wisconsin Trappers Association volunteers, and Tango the detection dog for field assistance. I also thank L. Bankson and the Bay Beech Sanctuary and J. London and the Irvine Park Zoo for donating bobcat scat. Funding for this project was provided by the Wisconsin Department of Natural Resources (WDNR), Citizen-based Monitoring Partnership Program of the WDNR, Wisconsin Trappers Association, Wisconsin Bear Hunters Association, Safari Club International, the Jack Massopust Memorial Scholarship, and the University of Wisconsin-Stevens Point (UWSP). B. Sloss and R. Franckowick of the Wisconsin Cooperative Fishery Unit at UWSP provided invaluable project support. J. Olson, R. Rolley, and B. Dhuey provided advice and WDNR data.

LITERATURE CITED

Anderson, E.M., and M. J. Lovallo. 2003. Bobcat and lynx. Pages 758-782 *in* Feldhammer, G.A., Thompson, B.C., Chapman, J.A. (Eds.), Wild Mammals of North America: Biology, Management, and Conservation, second edition. John Hopkins Press, Baltimore, MA, USA.

Aubry, K. B., and J. C. Lewis. 2003. Extirpation and reintroduction of fishers *(Martes penanti)* in Oregon: implications for their conservation in the Pacific states. Biological Conservation 114:79-90.

Benson, D. A., I. Karsh-Mizrachi, D. J. Lipman, J. Ostell and D. L. Wheeler. 2005. GenBank. Nucleic Acid Research 33:D34-D38.

Bluett, R. D., G. F. Hubert, Jr., and A. Woolf. 2001. Perspectives on bobcat management in Illinois. Pages 67-73 *in* A. Woolf, C. K. Nielsen and R. D. Bluett, eds. Proceedings of a symposium on current bobcat research and implications for management. Wildlife Society, Nashville, Tennessee.

Campbell, L. A., R. A. Long, and W. J. Zielinski. 2008. Integrating multiple methods to achieve survey objectives. Pages 224-237 *in* R. A. Long, P. MacKay, W. J. Zielinksi, and J. C. Ray, editors. Noninvasive survey methods for carnivores. Island Press, Washington, DC, USA.

Choate, D. M., M. L. Wolfe, and D. C. Stoner. 2006. Evaluation of cougar population estimators in Utah. Wildlife Society Bulletin 34:782-799.

Constable, J. L., M. V. Ashley, J. Goodall, and A. E. Pusey. 2001. Noninvasive paternity assignment in Gombe chimpanzees. Molecular Ecology 10:1279–1300

Curtis, J. T. 1959. The vegetation of Wisconsin. University of Wisconsin Press, Madison, USA.

Dhuey, B. 2008. Winter track counts, 1977 – 2008, Wisconsin Wildlife Surveys Report. Document on file at the Wisconsin Department of Natural Resources, Bureau of Research, Monona, WI

Diefenbach, D. R., M. J. Conroy, R. J. Warren, W. E. James, L. A. Baker and T. Hon. 1994. A test of the scent-station survey technique for bobcats. Journal of Wildlife Management 58:10-17.

Drummond, A. J., B. Ashton, M. Cheung, J. Heled, M. Kearse, R. Moir, S. Stones-Havas, T. Thierer, and A. Wilson. 2007. Geneious v3.0, Available from http://www.geneious.com/

Foran, D. R., K. R. Crooks, and S. C. Minta. 1997. Species identification from scat: and unambiguous genetic method. Wildlife Society Bulletin 25:835-839.

Harrison, R. L. 2006. A comparison of survey methods for detecting bobcats. Wildlife Society Bulletin 34:548–552.

Hoezel, A. R., and A. Green. 1992. Analysis of population-level variation by sequencing PCR-amplified DNA. Pages 159-187 *in* A. R. Hoelzel, editor. Molecular genetic analysis of populations: a practical approach. IRL Press, Oxford, UK.

Johnson W. E., Culver M., Iriarte J.A., Eizirik E., Seymour K., and O'Brien S. J. 1998. Tracking the elusive Andean mountain cat (*Oreailurus jacobita*) from mitochondrial DNA.. Journal of Heredity 89:227-232.

Kendall, K. C., and K. S. McKelvey. 2008. Hair collection. Pages 141-182 *in* R. A. Long, P. MacKay, W. J. Zielinksi, and J. C. Ray, editors. Noninvasive survey methods for carnivores. Island Press, Washington, DC, USA.

Kerley, L. L., and G. P. Salkina. 2007. Using scent-matching dogs to identify individual Amur tigers from scats. Journal of Wildlife Management 71:1349-1356.

Knick, S. T. 1990. Ecology of bobcats relative to exploitation and a prey decline in southeastern Idaho. Wildlife Monographs 108:3-42.

Lancia, R. A., J. D. Nichols, and K. H. Pollock. 1994. Estimating the number of animals in wildlife populations. Pages 215-253 *in* T. A. Bookhout, ed. Research and management techniques for wildlife and habitats. Fifth edition. The Wildlife Society, Bethesda, Maryland, USA.

Litvaitis, J. A., J. T. Major, and J. A. Sherburne. 1987. Influence of season and human-induced mortality jon spatial organization of bobcats (*Felis rufus*) in Maine. Journal of Mammalogy 68:100-106.

Livingston, T. R., P. S. Gipson, W. B. Ballard, D. M. Sanchez, and P. R. Krausman. 2005. Scat removal: a source of bias in feces-related studies. Wildlife Society Bulletin

Long, R. A., T. M. Donovan, P. Mackay, W. J. Zielinksi, and J. S. Buzas. 2007a. Effectiveness of scat detection dogs for detecting forest carnivores. Journal of Wildlife Management 71:2007-2017.

Long, R. A., T. M. Donovan, P. Mackay, W. J. Zielinksi, and J. S. Buzas. 2007b.Comparing scat detection dogs, cameras, and hair snares for surveying carnivores. Journal of Wildlife Management 71:2018-2025.

Lovallo, M. J. 1993. Bobcat behavior and home range use in northwestern Wisconsin: in reference to censusing populations. Thesis, University of Wisconsin, Stevens Point, Wisconsin.

Lovallo, M. J., and E. M. Anderson. 1996. Bobcat (*Lynx rufus*) home range size and habitat use in northwest Wisconsin. American Midland Naturalist 135:241-252.

McDaniel, G. W., K. S. McKelvey, J. R. Squires, and L. F. Ruggiero. 2000. Efficacy of lures and hair-snares to detect lynx. Wildlife Society Bulletin 28:119-123.

Mills, L. S., K. L. Pilgrim, M. K. Schwartz, and K. McKelvey. 2000. Identifying lynx and other North American felids based on MtDNA analysis. Conservation Genetics 1:285-288.

Moore, T. D., E. S. Liter, and C. E. Dugnolle. 1974. Identification of the dorsal guard hairs of some mammals of Wyoming. Wyoming Department of Game and Fish, Cheyenne, USA

Oka, T., and O. Takenaka. 2001. Wild gibbons' parentage tested by noninvasive DNA sampling and PCR-amplified polymorphic microsatellites. Primates 42:67–73..

Rolley, R. E. 1987. Bobcat. Pages 671-681 *in* M. Nowak, J. A. Baker, M. E. Obbard and B. Malloch, eds. Wild furbearer management and conservation in North America. Ontario Ministry of Natural Resources, Toronto.

Ruell, E. W. and K. R. Crooks. 2007. Evaluation of noninvasive genetic sampling methods for felid and canid populations. Journal of Wildlife Management 71:1690-1694

Shinn, K. J. 2002. Ocelot distribution in the Lower Rio Grande Valley National Wildlife Refuge. Thesis, University of Texas-Pan American, Edinburg, USA

Smith, D. A, K. Ralls, B. Davenport, B. Adams, and J. E. Maldonado. 2001. Canine assistants for conservationists. Science 291:435.

Smith, D. A., K. Ralls, A. Hurt, B. Adams, M. Parker, B. Davenport, M. C. Smith, and J. E. Maldonado. 2003. Detection and accuracy rates of dogs trained to find scats of San Joaquin kit foxes (*Vulpes macrotis mutica*). Animal Conservation 6:339–346.

Squires, J. R., K. S. McKelvey, and L. F. Ruggiero. 2004. A snow tracking protocol used to delineate local lynx distributions. Canadian Field-Naturalist 118:583-589.

Wasser, S. K., B. Davenport, E. R. Ramage, K. Hunt, M. Parker, C. Clarke, and G. Stenhouse. 2004. Scat detection dogs in wildlife research and management: application to grizzly and black bears in the Yellowhead Ecosystem, Alberta, Canada. Canadian Journal of Zoology 82:475–492.

Weaver, J. L., P. Wood, D. Paetkau, and L. L. Laack. 2005. Use of scented hair snares to detect ocelots. Wildlife Society Bulletin 33:1384-1391.

Van Dyke, F. G., R. H. Brocke, and H. G. Shaw. 1986. Use of road track counts as indices of mountain lion presence. Journal of Wildlife Management 50:102-109.

Zar, J. H. 1999. Biostatistical analysis. Fourth edition. Prentice-Hall, Upper Saddle River, New Jersey, USA

CHAPTER 3:

A COMPARISON OF ATTRACTANTS WITH CAPTIVE BOBCATS (*LYNX RUFUS*) FOR NON-INVASIVE SURVEYS

ABSTRACT

Non-invasive survey techniques such as scent stations and hair-snares can be used not only to document the presence and distribution of bobcats but give insights into demographic information as well. Key to these methods is the use of a lure that invokes interest and elicits a rubbing response. I compared six scent lures including 1) Russ Carmen's Canine Call, 2) Lenon's Nature Call, 3) Lenon's Super All Call, 4) O'Gorman's Powder River Cat Call , 5) beaver castor, imitation catnip oil, and dried catnip and 6) bobcat urine on 17 captive bobcats housed in 5 different facilities. I recorded behavioral responses to the lures including sniff, rub, roll, and reach. A higher proportion of bobcats responded to scent lures than the control ($p<0.05$), however, there was no difference ($p > 0.05$) in the proportion of bobcats that reacted when the six scent types were compared. Bobcats did sniff, rub, and roll more frequently ($p<0.05$) on SAC than the other lures, however, only 74% sniffed, 49% rubbed, and 41% rolled in response to SAC. The reduced probability of detection and the lack of difference between lures suggest a need for further lure testing with both captive and wild bobcats prior to large scale implementation.

INTRODUCTION

Bobcat populations are often surveyed with non-invasive methods such as scent stations and track surveys (Gese et al. 2001) These methods can be valuable tools to index population changes but low detectability, sampling error, and the preclusion of individual identity limit the information that can be gained (Squires et al. 2004). Hair snares are scented devices that non-invasively collect hairs from which individual identity can be genetically confirmed. Hair snares rely on scent lures to 1) attract the bobcat to the snare, and 2) entice the bobcat to rub on the snare.

Past studies have compared the efficacy of lures to attract felids to scent stations (e.g., Morrison et al 1981, Sumner and Hill 1987, Harrison 1997, Chamberlin et al. 1999) while more recent research has investigated the efficacy of an attractant to induce a rubbing response in lynx (*Lynx lynx*) (McDaniel et al. 2000) and ocelot (*Leopardus pardalis*) (Weaver et al. 2005). A limited number of studies have tested scent lures with penned bobcats, however the rubbing response was not specifically analyzed (Weaver 1997, E. Ruell, Colorado State University, personal communication).

Recent bobcat studies that employed hair snares with scent lures that were tested with lynx and ocelot, but not with bobcats, resulted in low visitation rates. Harrison (2006) detected bobcat hair at 1 out of 631 hair snares (0.0002%) over a 4-week period and Long et al. (2007) detected no bobcats from 74 hair snares over a 2-week period. Given that scent rubbing cues are often species-specific (Reiger 1979), it is important to employ attractants that have been tested specifically for the species of interest.

STUDY AREA

Captive bobcats were located at New Zoo (1M, 1F) and Bay Beach Sanctuary (1M, 1F) in Green Bay, Wisconsin; Irwin Park Zoo (1M, 1F) in Chippewa Falls, Wisconsin; Jo Don Farms (1M, 1F) in Franksville, Wisconsin; Valley of the Kings Sanctuary (1M) in Sharon, Wisconsin; and Big Cat Rescue (2M, 6F) in Tampa, Florida. Bobcats were kept in enclosed outdoor pens with access to indoor pens in Wisconsin facilities and in enclosed outdoor pens with natural vegetation in the Florida facility.

METHODS

Six different scent lures were tested: 1) bobcat urine (BU) (Minnesota Trapline Products), 2) beaver castor, imitation catnip oil, and dried catnip (BOC), 3) Russ Carmen's Canine Call (CC) (R. Carmen, New Milford, PA), 4) O'Gorman's Powder River Cat Call (C. O'Gorman, (PRCC), 5) Lenon's Super All Call (SAC) (Lenon's Animal Lures, Gulliver, Mich), and 6) Lenon's Nature Call (NC) . I chose BU and BOC based on previous studies (McDaniel et al. 2000, Harrison 1997), CC based on personal communication with E. Ruell and a study conducted by Ruell and Crooks (2007), PRCC based on personal communication with Eric Anderson, and NC and SAC based on personal communication with several Wisconsin trappers. Scent trials were conducted on 17 captive bobcats (10 F and 7 M) located in five private zoos in Wisconsin (n=4) and Florida (n=1). All scent trials were conducted in enclosed outdoor pens from Oct – Dec, 2007.

A cotton ball with 2 ml of liquid lure were presented in perforated film canisters and fastened to the outside of the pen with cable ties at a height of 1m (Fig. 1). Two captive facilities prohibited the fastening of lures to the pen; at these facilities film canisters were placed on the ground 0.5 meters from the pen's exterior perimeter. A perforated film canister containing a clean cotton ball was presented as a control lure. Lures were presented simultaneously and were separated from each other by 1 m. I randomized the presentation of the lures along the pen boundary for each trial so each bobcat was tested with a unique sequence of lures.

Bobcats were tested individually (n=11) except at facilities where captive conditions required simultaneously testing 3 pairs of bobcats (n=6). Each bobcat was presented with six lures plus the control for an observation period of 10 minutes. Behavioral responses to the lure were recorded at 15 second intervals following the one-zero method (Martin and Bateson 1986). Recorded behaviors included sniffing, reaching for the lure by sticking a paw through the cage, rubbing their head against the lure, rolling, licking the lure, or urinating on the lure (Fig. 2).

Figure 1. Scent trial consisting of 6 lures and 1conrol presented in perforated film canisters secured to fence 1m above the ground and 1 m apart in Wisconsin, USA.

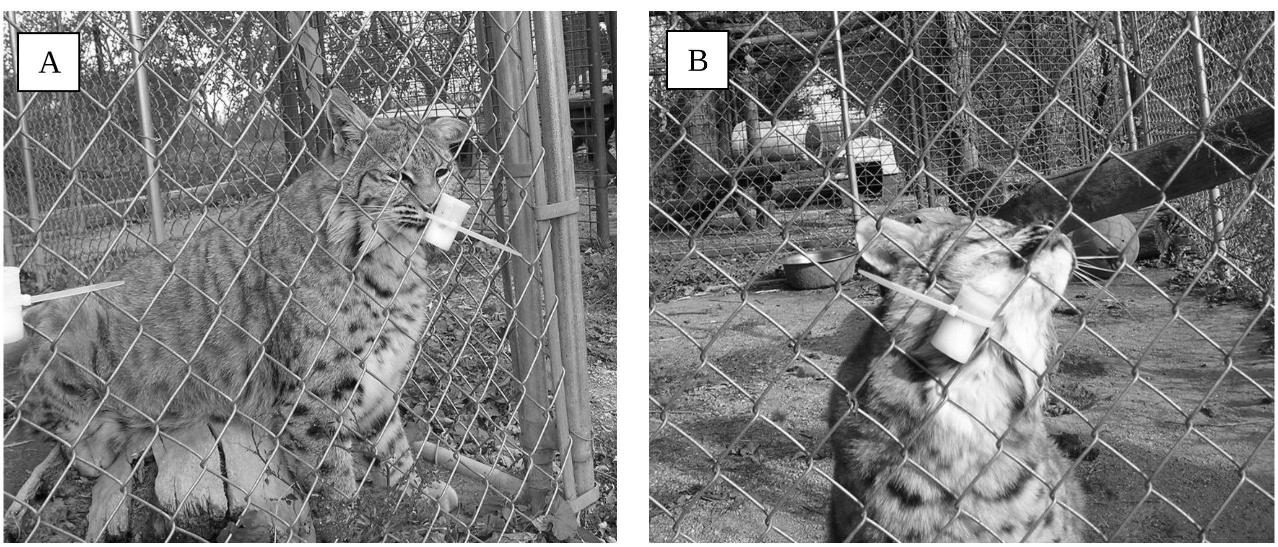

Figure 2. A) Sniffing and b) rubbing behaviors recorded in response to scent lures during scent trials in Wisconsin, USA.

A behavior was recorded if it occurred within the 15 second interval. The mean number of intervals in which bobcats exhibited behavior was compared among the lures with an analysis of variance (ANOVA) and further analyzed with Newman-Keuls multiple comparison test. For each behavior, I compared the proportions of bobcats that exhibited a response among the lures anytime during the 10-minute observation period using chi square test of independence (Zar 1999). If an association between variables was detected, *post hoc* testing was conducted to determine what categories (cells) were major contributors (Crewson 2006). Also for each behavior, I compared the proportion of bobcats that responded to scented lures to the proportion that responded to the control using Fisher's exact test (Zar 1999). Likewise, for each behavior I compared the proportion of female bobcats that responded to the proportion of male bobcats that responded using Fisher's exact test. I performed all statistical analysis ($\alpha = 0.05$) in SPSS (SPSS, Inc., Chicago, IL).

RESULTS

A significantly higher proportion of bobcats sniffed ($p < 0.001$), rubbed ($p < 0.001$), rolled ($p=0.001$) and reached ($p= 0.018$) in response to scented lures compared to the control. There were no detectable differences in the response of males or females to the lures within any behavioral category.

Table 1describes the percentage of bobcats that exhibited each behavior in response to each lure. There was no significant difference between any lures and the proportion of bobcats that sniffed ($\chi^2 = 8.341$, df = 6, $p = 0.214$), rubbed ($\chi^2 = 12.423$, df = 6, $p=0.053$) or reached ($\chi^2 = 5.409$, df = 6, $p=0.493$). There was a difference between lures that elicited a rolling response ($\chi^2 = 21.961$, df = 6, $p=0.001$). A *post hoc* analysis of standardized residuals of each cell in the contingency table suggests that SAC was positively associated with the roll response.

I detected a difference in the mean number of times bobcats sniffed ($p < 0.001$), rubbed ($p = 0.007$), and rolled ($p = 0.040$) among lures (Figure 3). There was no difference in the mean number of occurrences that bobcats reached (p = 0.160) among lures. The lick and urination behavior were removed from analysis because lick was observed only once and urination was not observed at all. Bobcats sniffed SAC, CC, PRCC, BOC, and BU with the greatest frequency. Bobcats rubbed SAC (11%) and BOC (4%) with the greatest frequency. Bobcats rolled in response to SAC, CC, and PRCC with the greatest frequency.

Table 1. Percentage of bobcats (n=17) that exhibited behavior at least once in response to lures during 10 minute trial at captive facilities in WI and FL.

Lure	Sniff	Rub	Roll	Reach
SAC	71%	47%	41%	6%
CC	59%	29%	29%	12%
PRCC	59%	24%	18%	18%
BOC	41%	35%	12%	18%
NC	41%	12%	0%	6%
BU	41%	6%	0%	6%
Control	29%	12%	0%	0%

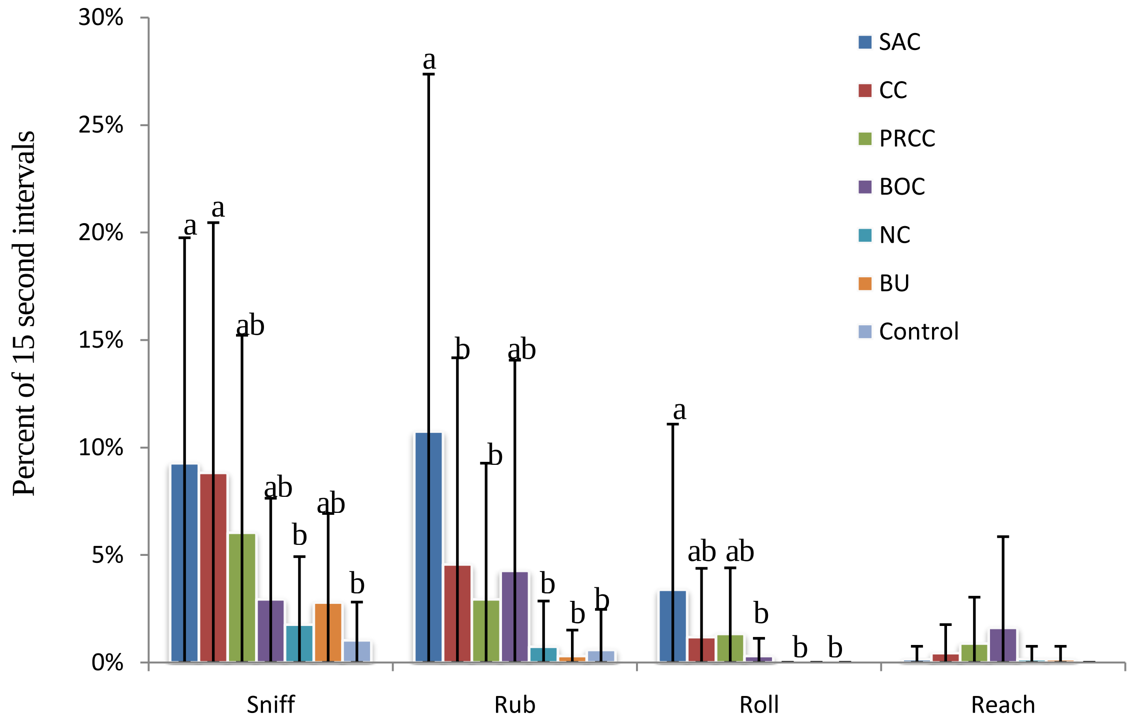

Figure 3. Average percent of intervals in which bobcats exhibited the behaviors of sniff, rub, roll, and reach in response to six lures and a control during ten minute trials. Bars represent one standard error. Values marked with the same letter within a behavior group are not significantly different (P<0.05).

DISCUSSION

While a higher proportion of bobcats responded to scent lures compared to the control, I was unable to detect differences between the efficacies of the lures for attracting bobcats. Although the scent lure that was the most attractive (SAC) enticed 71% of the sampled bobcats to sniff, only 47% rubbed. The low probability of detection may suggest an overall low visitation rate by bobcats to survey devices such as scent stations that require at least an investigative (sniff) response. A hair snare device that requires an active response (rub) from the bobcat has a less than 50% chance for detection while a scent station might attract less than three-quarters of passing bobcats. This contrasts with a previous felid study where 84% of captive ocelots rubbed in response to WLL (Weaver et al. 2005).

These results are similar to those of previous studies where no significant differences were found in bobcat visitation rates to scent stations in response to different scent lures including bobcat urine, synthetic fatty acid scent (FAS) tablets, and rhodium (Chamberlain et al. 1999, Morrison et al. 1981). In addition, Weaver (1997) found no significant difference in captive bobcat response to three different scent lures including catnip, musk oil, and Weaver's Lynx Lure (WLL). Small sample sizes, however, may have precluded the detection of differences between lures.

In contrast to the results of this study, Sumner and Hill (1980) found bobcats visited scent stations baited with bobcat urine significantly more than stations baited with other scents including FAS and red fox urine. Also, Harrison (1997) found bobcat urine elicited significantly higher behavior scores in several Central American felids. However in all of these studies, rubbing was never specifically measured.

Bobcat urine has had mixed success in its ability to attract bobcats to a scent station and low success in its effectiveness at inducing the rub response. Weaver et al. (2005) reported success with hair snares with radio collared ocelots using Weavers Cat Call (WCC) and Shinn (2002) reported finding bobcat hair on 12% of his ocelot hair snare sets using WCC; however WLL/WCC is no longer in production and could not be included in this study. Long et al. (2007) recovered zero bobcat hairs from hair snares using Weaver's lure. McDaniel et al. (2000) reported success with hair snares for lynx using a combination of beaver castor, catnip oil, and dried catnip on hair snares however Harrison (2006) reported minimal success using this lure for hair snares for bobcats. Finally, Ruell and Crooks (2007) reported moderate success in finding bobcat hairs on snares baited with Russ Carmen's Canine Call. Inconsistent results may potentially be because of unequal sampling intensity, differences in geographical location (e.g., same lure was used with differences in success with lynx in Colorado vs. bobcats in New Mexico), or species-specific olfactory cues.

A potential problem that may have hindered the results of this study may be that all 17 bobcats were tested in captive conditions. Limitations that may be associated with pen scent trials include: 1) captive bobcats may be more exposed or habituated to scents that would otherwise be novel to a wild bobcat, therefore reducing their possible interest in the scent, 2) bobcats that were tested at the same time in the same pen may have influenced each other's responses, and 3) a bobcat that was tested first in a shared pen may have influenced the behavior of the bobcat that was tested second in the same pen. Results from this study should be considered preliminary and future studies with wild bobcats would contribute toward increasing the efficacy and reliability of the hair snare technique for bobcats.

ACKNOWLEDGEMENTS

I thank A. Adams, M. Proctor, S. Roef, K. Schindler and S. Schmidt for field assistance. I also thank L. Bankson and the Bay Beech Sanctuary, J. London and the Irvine Park Zoo, C. Murach and the New Zoo, R. Myers and the Jo Don Farms, and J. Ruszczyk and Big Cat Recue for allowing me to test their captive bobcats. Funding was provided by the University of Wisconsin- Stevens Point.

LITERATURE CITED

Chamberlain, M. J., J. W. Mangrum, B. D. Leopold, and E. P. Hill. 1999. A comparison of attractants used for carnivore track surveys. Proceedings from the Annual Conference of South Eastern Association of Fish and Wildlife Agencies 53:296-304.

Crewson, P. 2006. Applied statistics handbook, Version 1.2. AcaStat Software.

Harrison, R. L. 1997. Chemical attractants for Central American felids. Wildlife Society Bulletin 25:93-97.

Harrison, R. L. 2006. A comparison of survey methods for detecting bobcats. Wildlife Society Bulletin 34:548-552.

Gese, E. M. 2001. Monitoring of terrestrial carnivore populations. Pages 372-396 *in* J. L. Gittleman, S. M. Funk, D. W. MacDonald, and R. K Wayne, eds. Carnivore Conservation. Cambridge University Press & The Zoological Society of London, Cambridge, Great Britain.

Long, R. A., T. M. Donovan, P. MacKay, W. Zielinkski, and J. S. Buzas. 2007. Comparing scat detection dogs, cameras, and hair snares for surveying carnivores. Journal of Wildlife Management 71:2018-2025.

Martin, P. and P. Bateson. 1986. Measuring behavior: an introductory guide. 1988, Reprint. Cambridge University Press, Cambridge, Great Britain.

McDaniel, G. W., K. S. McKelvey, J. R. Squires, and L. F. Ruggiero. 2000. Efficacy of lures and hair snares to detect lynx. Wildlife Society Bulletin 28:119-123.

Morrison, D. W., R. M. Edmunds, G. Linscombe, and J. W. Goertze. 1981. Evaluation of specific scent variables in north central Louisiana. Proceedings from the Annual Conference of South Eastern Association of Fish and Wildlife Agencies 35:281-291.

Reiger, I. R. 1979. Scent rubbing in carnivores. Carnivore 2:17-25.

Ruell, E. W. and K. R. Crooks. 2007. Evaluation of noninvasive genetic sampling methods for felid and canid populations. Journal of Wildlife Management 71:1690-1694.

Shinn, K. J. 2002. Ocelot distribution in the Lower Rio Grande Valley National Wildlife Refuge. Thesis, University of Texas-Pan American, Edinburg, USA.

SPSS. 2007. SPSS Version16.0.1 for Windows. SPSS Inc., Chicago, Illinois, USA.

Sumner, P. W. and E. P. Hill. 1980. Scent-station as indices of abundance in some furbearers of Alabama. Proceedings from the Annual Conference of South Eastern Association of Fish and Wildlife Agencies 34:572-583.

Squires, J. R., K. S. McKelvey, and L. F. Ruggiero. 2004. A snow tracking protocol used to delineate lynx distributions. Canadian Field-Naturalist 118:583-589.

Weaver, J. L., P. Wood, D. Paetkau, and L. L. Laack. 2005. Use of scented hair snares to detect ocelots. Wildlife Society Bulletin 33:1384-1391.

Weaver, J. L. 1997. Lynx survey and habitat assessment: Kootenai National Forest, Montana. Wildlife Conservation Society. Year 1 Progress Report.

Zar, J. H. 1999. Biostatistical analysis. Fourth edition. Prentice-Hall, Upper Saddle River, New Jersey, USA.

CONCLUSIONS

The Penrose distance model identified the majority of potentially suitable bobcat habitat as occurring in the harvest zone of northern Wisconsin in addition to isolated areas in central and southern Wisconsin. Percentage of upland forest, percentage of lowland forest, and edge density were most correlated to Penrose distance indicating their importance in determining bobcat habitat quality. However, the accuracy of the Penrose distance model was only collaborated by sighting data in the non-harvest zone. The poor performance of the model, even when evaluated against evidence only from the harvest zone, suggests the model may be inadequate to correctly identify bobcat habitat on anything more than a coarse level. Prior to implementing changes in the bobcat harvest regime, research should be conducted that examines bobcat-habitat relationships with radio-collared bobcats outside of the current harvest zone. In addition, future modeling efforts should take advantage of advances in remote sensing technology in an attempt to incorporate more abiotic landscape variables such as understory density and rocky outcroppings.

From the comparison of non-invasive survey methods, the scat-sniffing detector dog detected the most bobcat samples while the hair snares detected the least. An advantage of the detector dog method over the winter track counts was its ability to detect scat samples deposited over a longer period of time. The detection dog was the most expensive method per transect while the winter track-counts were the least expensive. Despite being the most expensive method, the cost per detection of the detector dog was comparable to the other methods do to its high detection rate. The poor detection rates of the hair-snares, compared to the detector dog and winter track count methods, may have occurred because in contrast to passive survey approaches such as detector dogs and winter track counts that do not require an induced response, hair snares require bobcats to alter their normal behavior by rubbing to collect a hair sample. Prior to further hair-snare studies to determine bobcat presence/absence or distribution, research could be conducted in known areas of bobcat abundance to reliably gage the effectiveness of hair-snares in comparison to other survey methods. Pilot studies should take place in similar habitat as the study area of interest. Until then, the detector dog may be the most appropriate method for determining bobcat presence/absence and potentially abundance in areas where winter track-counts are not feasible.

The poor performance of the hair-snares resulted despite conducting scent trials with captive bobcats prior to the field season with the objective of finding a scent lure that would better induce the rubbing behavior. While a higher proportion of bobcats responded to scent lures compared to the control during the trials, I was unable to detect differences between the efficacies of the lures for attracting bobcats. The scent lure that was the most attractive (SAC) enticed only 71% of the sampled bobcats to sniff, and only 47% to rub. The low probability of detection may suggest an overall low visitation rate by bobcats to survey devices such as scent stations that require at least an investigative (sniff) response. Based on results from the most successful lure from the scent trials, a hair snare device that requires an active response (rub) from the bobcat has a less than 50% chance for detection while a scent station might attract less than three-quarters of passing bobcats. Future studies that tested scent-lures with wild, rather than captive bobcats, would contribute toward increasing the efficacy and reliability of the hair snare technique for bobcats.

My research efforts should assist resource managers in recognizing the need for a different management approach for the non-harvest zone than what is used in the harvest zone. The extensive range of the bobcat and it's varied habitat associations across large geographic areas, such as Wisconsin, may preclude the use of large landscape-scale modeling approaches and a single statewide survey approach. Separate models for central and southern Wisconsin, combined with a survey approach that integrates multiple methods may increase the overall probability of detection, leading to less biased estimates of occurrence and abundance.