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AN EVALUATION OF CITIZEN SCIENCE-BASED INDICES FOR MONITORING THE DISTRIBUTION AND ABUNDANCE OF BOBCATS (LYNX RUFUS)

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AN EVALUATION OF CITIZEN SCIENCE-BASED INDICES FOR MONITORING THE DISTRIBUTION AND ABUNDANCE OF BOBCATS (*LYNX RUFUS*)

BY

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DEDICATION

This thesis is dedicated to my grandfather, Peter E. Spangeberg, from whom I inherited a compulsion to figure out how things work.

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ABSTRACT

AN EVALUATION OF CITIZEN SCIENCE-BASED INDICES FOR MONITORING THE DISTRIBUTION AND ABUNDANCE OF BOBCATS (*LYNX RUFUS*)

by

Tyler J. Mahard

University of New Hampshire, December, 2014

Carnivores substantially impact humans, but are elusive and difficult to monitor. Although less precise than intensive methods (e.g., capture-recapture), indices of relative abundance are widely used to monitor carnivore numbers. This study assessed public sightings and hunter surveys as approaches to monitoring the distribution and relative abundance of bobcats (*Lynx rufus*) in New Hampshire. To validate indices, I used a telemetry-based model of habitat suitability and information from camera surveys conducted by volunteers in three study areas. Bobcats were found widely distributed in New Hampshire with lower abundance in northern and mountainous regions. Public sightings and hunter surveys (both effort-corrected) were strongly correlated to each other and the suitability model when summarized by Wildlife Management Unit. Detection rates from camera surveys were correlated to other indices and the model within the three study areas. I suggest future research validate indices using absolute abundance, and assess influences of confounding variables.

CHAPTER 1

INTRODUCTION

Monitoring changes in the distribution and abundance of wildlife populations is vital for managing relationships between wildlife and people. Monitoring is achieved through repeated documentation of the occurrence of animals throughout an area of interest (Thompson et al. 1998). Distribution (where a species occurs) and abundance (number of individuals) indicate a population's status and responses to environmental factors. Factors including harvests (Litvaitis et al. 2006), urban development (Fahrig 1997), road traffic (Seiler and Helldin 2006), pollution (Newman 1979), and prevalence of invasive species (Pimentel et al. 2005) cause observable changes in wildlife populations and are anthropogenic in origin. Natural factors, such as winter severity (Delgiudice et al. 2002), changes in habitat composition (Hodorff et al. 1988), predation (Bulmer 1974), and competition (Litvaitis and Harrison 1989) may also elicit responses. Detecting fluctuations in distribution and abundance through monitoring can reveal how these factors influence wildlife and reach a point of concern that warrants management action.

Due to their profound interactions with humans, carnivores represent an important taxon to monitor (Treves and Karanth 2003, Inskip and Zimmermann 2009), but present substantial challenges due their elusive natures and low population densities (Gompper et al. 2006, Long et al. 2008). Assessing their distribution requires logging locations of occurrence. These may be based on kills (Richens and Hugie 1974), observations (Broman et al. 2014), or physical evidence (e.g., tracks or feces; McDaniel et al. 2000). A comprehensive assessment of distribution also requires knowing where a species does not occur. This is achieved through systematic surveys that assess presence versus absence (e.g., Long et al. 2011). For carnivores, this may involve searching for tracks (Zielinski et al. 1995), scats (Palomares et al. 2002), or other evidence of occurrence. Recently, motion-triggered cameras have become a popular and cost-effective tool for detecting carnivores (O'Connell et al. 2011).

In contrast, assessing abundance generally requires more information. Capture-recapture, a common approach, involves sampling multiple groups of individuals and uses the proportion of resampled individuals in subsequent samples to estimate population size (White et al. 1982). Intensive approaches such as this provide accurate estimates of abundance, but generally are limited in spatial scope due to high effort and costs (e.g., Mowat and Strobeck 2000, Trolle and Kéry 2003, Coster et al. 2011, Goswami et al. 2011).

Extensive approaches frequently rely on an index of relative abundance that involves monitoring a parameter assumed to be correlated to abundance (Thompson et al. 1998, Engeman 2005, O'Brien 2011). Examples include occurrences of frog calls (Royle 2004), bandicoot road-kills (Mallick et al. 1998), and bobcat harvest counts (Nunley 1978). Because such variables are usually easy to tally, indices are used for large areas (Rolley 1985, Barea-Azcón et al. 2006, Cooper et al. 2012). However, confounding variables (i.e., factors other than animal abundance) may influence index values, and are often difficult to control (Pollock and Nichols 2002, MacKenzie 2006). For example, bandicoot road-kill rates could be influenced by factors such as road density, traffic volume, and the tendency of bandicoots to cross roads, all of which may change over time or vary from one region to the next. However, Mallick et al. (1998) incorporated traffic volume to standardize the index, and comparisons were made across equal-length stretches of road. As a result, they observed substantial agreement between numbers of bandicoots killed on roads (adjusted for traffic volume) and those captured in trapping grids over a four-year period. Similar to this, time spent hunting has been documented as 'survey effort', and used to standardize indices of abundance based on numbers of wildlife sightings by hunters (Solberg and Saether 1999, Cooper et al. 2012).

Geographic models that use environmental variables to predict abundance or habitat suitability are an additional extensive approach. Locations of individuals obtained from telemetry collars (Roberts et al. 2010), incidental observations (Woolf et al. 2002, Linde et al. 2011), or both (Reed 2013) have been used to characterize relationships between environmental variables and habitat suitability. Environmental variables are generally restricted to those easily described throughout an area of interest (e.g., elevation, forest type, road density). This allows for modeling of abundance, distribution, or habitat suitability throughout an entire area of interest, and the species of interest needs to be documented in only a portion of that area (DeCesare et al. 2012, Sequeira et al. 2014).

A system for collecting information on species occurrence is an essential component of any monitoring effort. This may be costly when assessing abundance across a large area. However, recent advances in technology (i.e., internet, geographic positioning systems, smartphones) have made it easier for members of the public to become citizen scientists and participate in data collection (Silvertown 2009, Dickinson et al. 2012). Citizen science offers a means for boosting survey effort with low cost, making it a boon for the detection of elusive species (Watkins and Moskowitz 2007, Erb et al. 2012, Nagy et al. 2012, Sequeira et al. 2014). Often, hunters are solicited, as they do not need additional incentives to enter wildlife habitats (Woolf et al. 2002, Kindberg et al. 2009, Rich et al. 2013). Because hunters are often required to correspond with state wildlife agencies (e.g., obtaining permits or harvest tags), much of the infrastructure for data collection is in place. Such is the case in New Hampshire, where hunters and other members of the public have been enlisted to collect information on bobcats (*Lynx rufus*).

After a suspected decline in bobcat numbers that coincided with land-use changes in the 1900s (Litvaitis et al. 2006), public sightings and vehicle collisions suggested that populations had since expanded in New Hampshire (Broman et al. 2014), as in other regions (Roberts and Crimmins 2010). Establishment of baseline data on the current distribution and abundance of bobcats in New Hampshire is needed to determine how these populations are responding to ongoing environmental changes.

New Hampshire's mean annual temperature has been steadily increasing over the past century (NOAA, Silver Spring, MD). Because cold temperatures (Mautz and Pekins 1989) and deep snow (McCord 1974) may limit bobcats (Fox 1990), warming is expected to result in further range expansions, and possibly encroachment into the range of federally-threatened Canada lynx (*Lynx canadensis*). Bobcats are believed to displace lynx in areas of sympatry (Peers et al. 2013), and hybridization, though rare (Koen et al. 2014), could facilitate absorption of lynx into expanding bobcat populations. Expansion and migration of bobcat populations in northern New Hampshire could pose a threat to conservation plans in neighboring Maine, where the US Fish and Wildlife Service has designated areas of critical habitat for lynx (Fish and Wildlife Service 2014).

Wildlife conservation efforts for numerous species can benefit from information on the distribution and abundance of bobcats. As top carnivores, the presence of bobcats indicates habitat that supports prey, particularly deer (*Odocoileus virginianus*) and smaller mammals (e.g., lagomorphs) (Litvaitis et al. 1984). This, and the fact that bobcats require large areas to procure enough prey make them an appropriate focal species for conservation efforts (Crooks 2002, Rubino and Hess 2003). The Nature Conservancy's "Staying Connected" initiative, which seeks to preserve habitat linkages in the northeastern United States, has identified bobcats as a "Species of Greatest Conservation Need" in this region (The Nature Conservancy 2013). The initiative identified habitat fragmentation, degredation, and conversion, as well as transportation corridors, as major drivers of habitat loss for bobcats and other carnivores. The steady increase in New Hampshire's human population over the past century (U.S. Census Bureau, Suitland, MD) suggests that these drivers will likely continue to threaten wildlife habitat.

In addition to potential impacts on lynx, and relevance to conservation planning, changes in the distribution and abundance of bobcats are important because bobcats have an impact on people. Anecdotal evidence in New Hampshire and other regions (Harrison 1998) suggests that people living in areas with bobcats are mostly fond of them. Regarded as rare and beautiful, bobcats invoke a sense of awe and wonder in humans that encounter them. On the other hand, bobcats may invoke fear, frustration, and hatred as they are occasionally predators of livestock and pets (Hansen 2007, Inskip and Zimmermann 2009). This notion of bobcats as varmints, along with the fur trade, encouraged trapping in the past (Litvaitis et al. 2006). If bobcat populations increase in New Hampshire, members of the public may push for trapping and hunting seasons to reopen. The listing of bobcats under Appendix II of the Convention on the Trade in Endangered Species of Wild Fauna and Flora requires that sufficient information exists to indicate that harvests do not jeopardize bobcat populations (Convention on the Trade in Endangered Species of Wild Fauna and Flora, 2014). Thus, a monitoring program for bobcats in New Hampshire will become essential if harvests resume.

Over the past five years, the New Hampshire Fish and Game Department has collected numerous records of bobcat observations through hunter surveys. Concurrently, researchers at the University of New Hampshire have been logging incidental observations of bobcats reported by the general public (public sightings). Both datasets are statewide in scope and convenient for generating indices of relative abundance. However, because relationships between parameters for abundance and animal abundance tend to change across time and space, indices should not be assumed to reflect relative abundance unless validated by intensive estimates of absolute abundance (Conn et al. 2004, O'Brien 2011). Due to high costs, a common approach is to validate an index in a few disjunct study areas, rather than an entire area of interest (Rovero and Marshall 2009). But, when the species of interest is elusive, costs may still be too great. For example, searches for bobcat scats in an effort to generate DNA-based capture-recapture abundance estimates for New Hampshire revealed that scat detection rates were too low to make the approach cost-effective (J. Litvaitis, University of New Hampshire, unpublished data).

Photographic capture-recapture estimates using individual recognition have been used to estimate bobcat abundance in other regions (Heilbrun et al. 2006, Larrucea et al. 2007), and may be more cost effective than DNA-based approaches (Clare 2013). However, low detection rates of bobcats by camera surveys in Vermont (adjacent to New Hampshire) suggest this could be infeasible as well (Moruzzi et al. 2002, Long et al. 2007, 2011). In lieu of rigorous abundance estimates, comparison of indices to each other and to predictive geographic models (e.g., Cooper et al. 2012) is the most appropriate approach to validate indices.

Based on the logistical difficulties associated with estimating the absolute abundance of bobcats in New Hampshire, comparison of indices based on hunter surveys and public sightings to indices based on detection rates from camera surveys, and a model of bobcat habitat suitability, may be the most practical method to evaluate current monitoring systems. Conveniently, a model of bobcat suitability has recently been developed for New Hampshire (Reed 2013). The model used the relationship between locations of bobcats (from GPS-collars and public sightings) and several environmental variables to describe habitat suitability statewide.

Objectives

Through assessment of indices, my goal was to provide information useful in the development of monitoring protocols that would be practical, low cost, and able to reveal changes in the distribution and abundance of bobcats in New Hampshire. I evaluated citizen science-based indices (public sightings and hunter surveys) in an assessment of the current distribution and relative abundance of bobcats in New Hampshire. Citizen observations of bobcats were logged by township to determine distribution and by larger wildlife management units to determine relative abundance. To validate indices from citizen observations, volunteers conducted camera surveys over an expected gradient in bobcat abundance across three study areas. Abundance indices were also compared to a habitat suitability index for New Hampshire developed by Reed (2013), under the assumption that abundance would be higher in more suitable habitat. Agreement among indices was assessed by correlation. Specific objectives included the following:

1. Evaluate the utility of citizen observations to assess the statewide distribution of bobcats.
2. Develop methods to account for sampling effort for citizen observations of bobcats.
3. Compare agreement among indices of bobcat abundance based on public sightings, hunter surveys, camera surveys, and a model of bobcat habitat suitability.
4. Provide recommendations to enhance the precision of statewide bobcat monitoring efforts.

CHAPTER 2

METHODS

Study Area

New Hampshire (24,217-km^2) is near the northern limit of the geographic range of bobcats (Fig. 2-1) and contains uninhabited townships in the White Mountains as well as densely populated cities (e.g., Manchester, Nashua). The state's human population increased from 1,316,470 in 2010 to 1,323,459 in 2013 (U.S. Census Bureau). The White Mountains span central New Hampshire and contain the state's maximum elevation, 1917 m at the summit of Mount Washington. The state is approximately 78% forested, with an abundance of mixed forests including white pine (*Pinus strobus*), eastern hemlock (*Tsuga canadensis*), red oak (*Quercus rubra*), and American beech (*Fagus gradifolia*) as dominant species (Justice et al. 2002). Development, agriculture, open water, wetlands, and cleared land each account for ~3-6% of total area (Justice et al. 2002).

Sympatric carnivores that may affect the distribution and abundance of bobcats in New Hampshire include lynx (*Lynx canadensis*), coyotes (*Canis lantrans*), red foxes (*Vulpes vulpes*), gray foxes (*Urocyon cinereoargenteus*), and fishers (*Martes pennanti*). White-tailed deer (*Odocoileus virginianus*), cottontails (*Sylvilagus spp.*), snowshoe hares (*Lepus americanus*), gray squirrels (*Sciurus carolinensis*), red squirrels (*Tamiasciurus hudsonicus*), and other small mammals constitute the bulk of bobcat prey (Litvaitis et al. 1984).

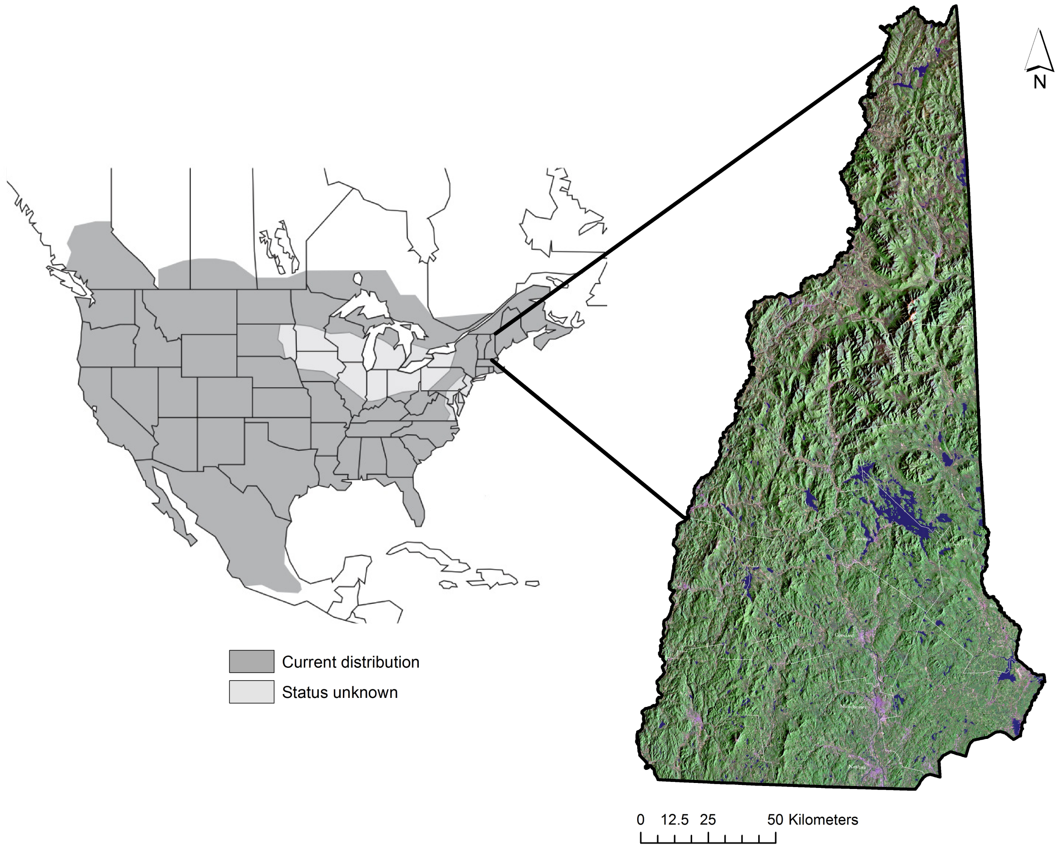


Figure 2-1. New Hampshire within the geographic range of bobcats (adapted from Hansen 2007). Satellite imagery (right) derived from Landsat 7 data and National Elevation Dataset, acquired July 1999 – September 2002, U.S. Geological Survey. Purple indicates developed land.

Spatial Scales for Distribution and Relative Abundance

Distribution, or where a species is found, may be expressed as either the ‘extent of occurrence’ or ‘area of occupancy’ (Gaston 1991). Extent of occurrence is the area bounded by the outermost limits beyond which a species is no longer found, whereas area of occupancy describes where the species exists within the extent of occurrence. In contrast to these, relative abundance is a measure related to the number or density of individuals such that differences in abundance between regions or over time may be inferred.

As New Hampshire is contained within the extent of occurrence for bobcats, I sought to describe the area of occupancy statewide. Because citizen observations included township of occurrence, townships served as convenient spatial units to identify regions where bobcats existed and regions where they may have been absent. Due to its irregularly large size (754 km^2), the township of Pittsburgh was divided into two spatial units using the WMU boundary between A1 and A2 (Appendix G). This provided 260 spatial units ranging in area from 2 to 393 km^2 ($\bar{x}$ = 88 km^2; Complex Systems Research Center, Durham, NH). Because a township of average size could contain at most 3-4 exclusive female bobcat home ranges of average size (23.8 km^2; Reed 2013), I expected random variation among the frequencies at which individual bobcats were observed to confound abundance indices at this scale. Given the small size of townships, and the small number of bobcat observations produced by each, presence-absence was the most appropriate monitoring approach (Pollock 2006). I could not control or sufficiently estimate the distribution of survey effort by citizen observers within townships, thus townships that did not produce bobcat observations were considered to have unknown status.

Larger wildlife management units (WMU; 302–2407 km^2; $\bar{x}$ = 1002 km^2) were used to describe relative abundance. This allowed for index values based on larger sample sizes, and I expected less influence from confounding variables. Further, WMUs are predominantly bounded by major highways, which may act as substantial barriers to bobcat dispersal (Riley et al. 2006). Many factors that affect bobcat abundance (e.g., land use, climate, forest types, topography, and human densities) were used to delineate WMUs. Thus, WMUs provide convenient strata for managing and assessing the abundance of bobcats because conditions relevant to bobcats are expected to be similar within a given WMU.

Sources of Information

I obtained citizen observations of bobcats from incidental public sightings (PS) and hunter surveys (HS) statewide from 2009 through 2013. To validate these indices, camera surveys (CS) for bobcats were conducted in a restricted portion of the state in 2013, and a habitat-based index was generated from a model of bobcat habitat suitability (MHS) for New

Hampshire developed by Reed (2013). Although indices should be calibrated using rigorous estimates of absolute abundance, this was financially and logistically infeasible. Because some regions of the state produced scarce PS and HS, citizen observations were summed over the five-year period to maximize the spatial scope within which distribution and abundance could be inferred. For some regions, distribution and abundance could not be estimated due to low survey effort and few bobcat observations. A potential disadvantage of aggregating 5 years of data is that temporal variation in abundance and effort could have resulted in inaccurate indices of relative abundance. For example, if effort in a given region was skewed toward the early portion of the 5-year period, and bobcat numbers were consistently increasing in that region, the resulting index value would be more representative of the first few years rather than the entire period.

Public sightings (PS)

Reports of observations of bobcats were collected from the general public through emails solicited by a university website (mlitvaitis.unh.edu/Research/BobcatWeb/bobcats.htm) from April 2009 through March 2014. Observers were requested to report their name and the date, time, township, exact location, observation type (i.e., seen, tracks, trapped, road kill, other), and bobcat's activity for each observation. Multiple observations from the same observer in the same location on the same day were counted as one sighting, as were sightings of multiple bobcats by one observer at one time. Sightings that occurred outside of the collection period or for which the date was not indicated were excluded. Township and WMU (Appendix G) of each occurrence were determined based on the reported township and location description provided by the observer (Appendix D). Records for which the location described by the observer did not match the reported township were excluded, unless the location was just outside of the reported township and it was obvious that the observer had unknowingly crossed a township boundary. In this scenario I recorded the township that corresponded to the location described by the observer.

Observations were screened to remove records that were more likely to be a product of an observer witnessing something (or the sign of something) other than a bobcat (McKelvey et al. 2008). Reports of bobcats based on sound or tracks were excluded. Reports for which the observer expressed uncertainty that the observed animal was a bobcat, and reports for which the observer described physiological features that were not bobcat features were also excluded. Photographs of bobcats and information to assist observers in identifying bobcats were provided on the project website. Screened sightings that occurred from April 1, 2009 through March 31, 2014 were summed by township and by WMU to assess distribution and abundance, respectively

Hunter surveys (HS)

New Hampshire Fish and Game Department (NHFG) mailed survey cards to registered deer hunters before the start of each deer season from 2009 through 2013 (Appendix E). Hunters were asked to record the date, WMU, township, duration in hours, and number of deer, bears, moose, and bobcats seen for each of their hunting outings during the season. Records for which the reported WMU and township were not spatially coincident, or for which the entry in the “town” field could not be matched to a township in the New Hampshire Political Boundaries spatial dataset (Complex Systems Research Center, Durham, NH), were excluded from analyses. When summarizing by WMU, records for which the WMU was not fully specified (e.g., “A” instead of “A1” or “A2”) were excluded unless the fully specified WMU could be inferred based on the reported township and the geography of its boundary (Appendix G). The number of hunter outings during which one or more bobcats were observed were summed by township and by WMU to assess distribution and abundance, respectively.

Camera surveys (CS)

Trail-camera surveys were conducted by citizen scientists in WMU H2S, I2, and M in November and December of 2013. These WMUs were selected as study areas based on hunter survey data collected from 2009 through 2012 (Appendix B). Relative to other WMUs, I2, H2S, and M had high, medium, and low observation rates of bobcats (bobcats observed per hunter hour), respectively, from 2009 through 2012. I expected to observe the same trend in camera detection rates of bobcats. Although I expected substantial volunteer recruitment based on high public interest in bobcat research (P. Tate, New Hampshire Fish and Game Department, personal communication), low detection rates of bobcats were anticipated, making a capture-recapture approach impractical. Thus, detection rates were used as an index of relative abundance. This was a major concern because use of an index to validate other indices (i.e., those based on hunter surveys and public sightings) is far from an ideal approach, as confounding variables that are difficult to estimate and control influence all indices.

Volunteers were recruited through emails and press releases from NHFG, and announcements on the bobcat project webpage (mlitvaitis.unh.edu/Research/BobcatWeb/bobcats.htm) and NHFG Facebook page. Prior to camera surveys, volunteers attended training sessions where they received attractant kits, watched a demonstration of camera setup, and asked questions. All volunteers received a protocol that explained camera and attractant setup (Appendix C). I selected attractants that successfully detected bobcats in this region (Long et al. 2011, Wellington et al. 2014). Attractants included Caven's "Gusto" Long Distance Call Lure (Minnesota Trapline Products, Pennock, MN) mixed with petroleum jelly and smeared to a tree, a fiberglass wick soaked in catnip oil imitation (F&T Fur Harvesters Trading Post, Alpena, MI), and half of a 15-cm foil pie tin suspended from a tree branch.

Prior to volunteer recruitment, 60 13.3-km^2 survey units were selected for each study area in an effort to promote even camera distribution and standardize study area size between the three WMUs. In an effort to maximize detection rates, survey units were selected by overlay with a model of bobcat habitat suitability (Reed 2013) and selection of the 60 grid cells that contained the most land area with a habitat suitability ranking >0.4 (Fig. 2-2, suitability model description to follow). Efforts were organized into three survey periods (Nov 1^{st}–16^{th}, Nov 15^{th}–Dec 2^{nd}, Nov 29^{th}–Dec 16^{th}). Volunteers were asked to identify a survey unit to deploy one camera station in prior to the start of each survey period. Volunteers who wished to deploy multiple cameras simultaneously were asked to select multiple survey units. Updated maps that showed available survey units were continually provided to volunteers to avoid multiple camera stations in one unit. Volunteers were asked to move their cameras to a new survey unit for each subsequent survey period, and were encouraged to select units that had not yet been surveyed.

For each camera station deployed, volunteers were asked to report the study area, survey unit, make and model of the camera, deployment and collection dates, geographic coordinates of the camera with an error estimate if available, a written description of the camera's location, comments on camera settings, and confirmation that the protocol was followed. Verbal descriptions of locations and hyperlinks to online mapping sources were accepted from volunteers who were unable to obtain coordinates from a GPS unit and spatial uncertainty was estimated using the methods described for determining coordinates of PS locations (Appendix D). Photos were primarily collected via internet cloud; some volunteers preferred to mail a CD containing image files. Volunteers were asked to submit all photographs collected by their cameras during the survey.

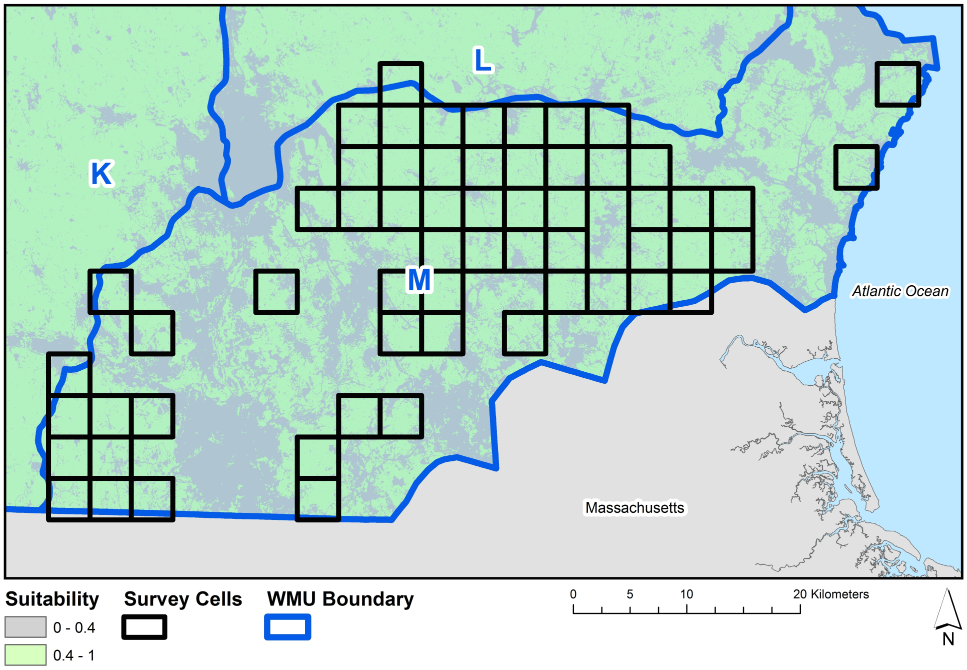


Figure 2-2. Method for determining locations of grid cells selected by citizen scientists for trail camera surveys. The map shows 60 13.3-km^2 grid cells arranged about WMU M (Study Area C) and overlain on a model of bobcat habitat suitability (Reed 2013) such that the amount of land area with habitat suitability >0.4 is roughly maximized. This was repeated in WMU H2S and I2 (Appendix B).

Model of habitat suitability (MHS)

A model of habitat suitability (MHS) for bobcats in New Hampshire was developed by Reed (2013). The model ranked 30-m raster cells covering the state on a scale of increasing suitability from 0 to 1. At a coarse resolution, raster rank was influenced by the locations of 665 public sightings (collected December 2007 through January 2013) in relation to mean monthly snow depth and elevation. At a fine resolution, raster rank was influenced by habitat selections of 18 GPS-collared bobcats in relation to 10 environmental variables expected to influence probability of bobcat use (see Table 2-1 of Reed 2013). The MHS was used to determine a habitat suitability index (HSI) value for each township and WMU by taking the average raster value of all raster cells coincident with land area in each WMU. Open water was excluded using NH Land Cover Assessment 2001 data (Complex Systems Research Center, Durham, NH). Processing of geospatial data was accomplished using ArcMap 10 software (ESRI, Redlands, CA) and the Spatial Analyst extension.

Sources of Error and Sampling Effort

Because township and WMU boundaries did not coincide, it was often necessary to pinpoint locations of PS on a map to determine corresponding WMUs. Due to wide variability in the amount of location detail provided by observers, I used a modification of methods developed by Wieczorek et al. (2004) to estimate a measure of spatial uncertainty for each pinpointed location (see Appendix D for details). If the spatial uncertainty was greater than the distance between the pinpointed location and the nearest WMU boundary, WMU was marked "unknown". In accordance with the methods of Wieczorek et al. (2004), records that contained dubious, unidentifiable, or contradicting locality descriptions (e.g., "town of Concord?") were excluded.

Location bias in favor of roads and human developments was anticipated among PS (Broman et al. 2014). Preliminary analyses indicated that most PS occurred in backyards and where bobcats crossed roads. Thus, total road length was used as a parameter for effort for each WMU. Because major highways defined many WMU boundaries, I excluded roads that ran along boundaries when calculating total road length for each WMU.

For HS, the number of outings during which bobcats were observed (O_B) was used as a parameter for abundance, and number of hunter outings (O) was used as a parameter for effort. Using O_B instead of the number of bobcats observed was expected to reduce bias due to chance encounters of bobcat family groups, and from repeated observations of the same individual during one hunting outing. Although hunters reported the number of hours they spent during each outing, I felt that O was a better parameter for effort (contrary to Kindberg et al. 2009, Linde et al. 2011, and Cooper et al. 2012). This was based on the notion that a high number of hunter outings in different locations would produce more bobcat observations than a lower number of longer outings, given an equal number of total hunter hours in each scenario. With fewer outings, the probability of a bobcat being in an area covered by a hunter would be lower. Supporting this, linear least squares regression revealed that O explained variation in O_B

(r^2=0.84, P<0.05) slightly better than did hours (r^2=0.83, P<0.05), using 24 summaries of HS records as observations (summed across all five years for each of 24 WMUs).

For CS, detection rate was calculated as the number of bobcat detections per trap night (TN). A detection was counted for each sequence of bobcat photographs in which all photographs were separated by <0.5 hours from others (similar to Kelly and Holub 2008). TN were calculated by summating the number of 24-hour periods of surveillance accomplished by each camera (similar to Karanth et al. 2006).

For PS, HS, and CS, parameters for effort were positively correlated to parameters for abundance (Fig. 2-3, 2-4, 2-5), supporting the idea that effort parameters were substantially driving abundance parameters.

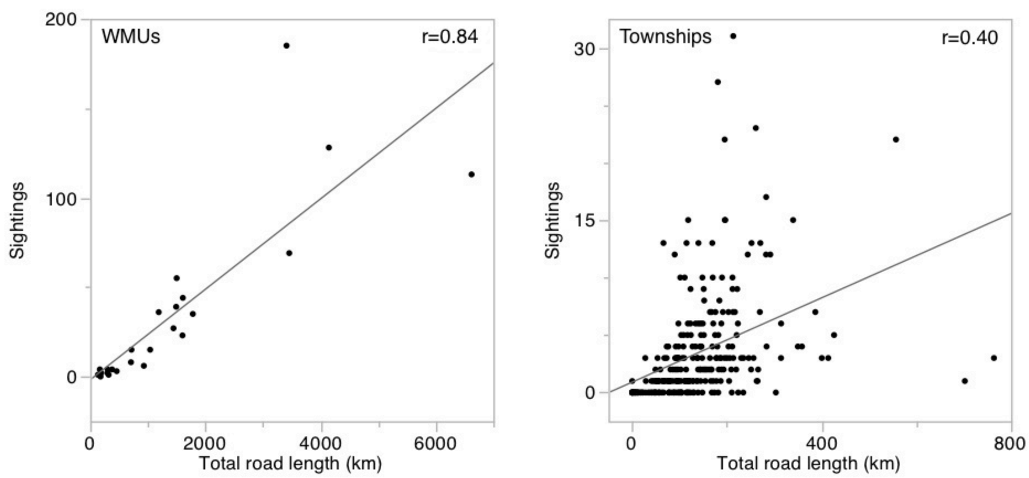


Figure 2-3. Correlation between a parameter for bobcat abundance (Sightings) and a parameter for effort (Total road length, km) for the public sightings index. Sample units consisted of 24 WMUs (left), and 260 townships (right), with the town of Pittsburg divided into two units. '*Sightings'* include all screened descriptions of bobcat observations sent to University of New Hampshire website from April 2009 through March 2014. Data on road lengths were obtained from the New Hampshire Department of Transportation (Concord, NH).

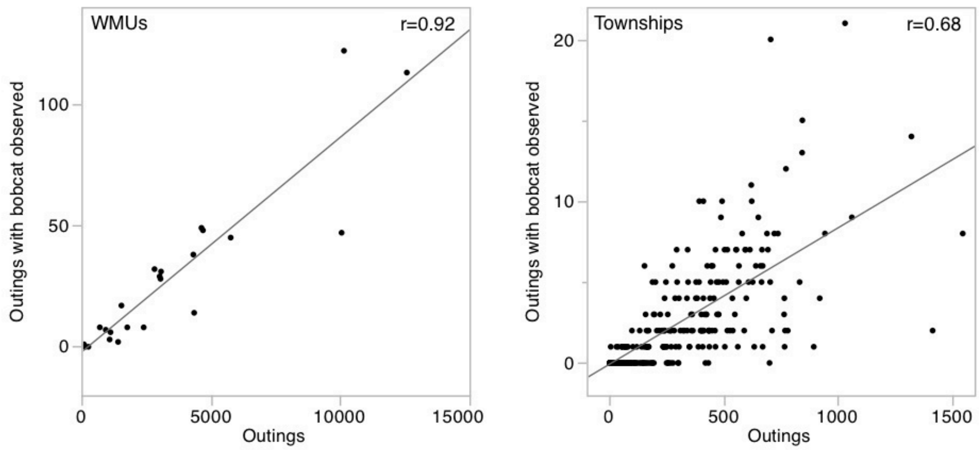


Figure 2-4. Correlation between a parameter for bobcat abundance (Outings with bobcat observed) and a parameter for effort (Outings) for the hunter survey index. Sample units consisted of 24 WMUs (left), and 260 townships (right), with the town of Pittsburg divided into two units. All parameters were summarized from records of hunter outings collected by the New Hampshire Fish and Game Department from 2009 through 2013.

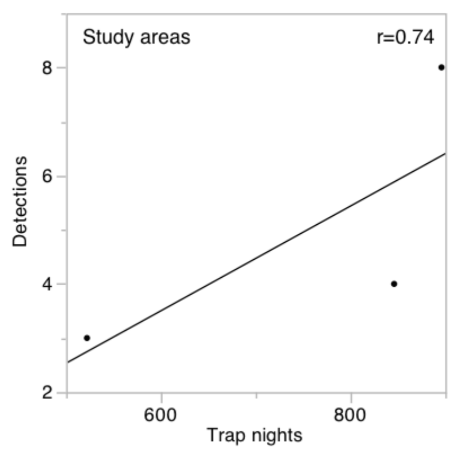


Figure 2-5. Correlation between a parameter of bobcat abundance (Detections) and a parameter for effort (Trap nights) for three study areas in southern New Hampshire. Data was derived from camera surveys conducted by citizen scientists in southern New Hampshire from 1 November 2013 through 16 December 2013.

Assessing Distribution of Bobcats from Indices

Townships that had 1 or more records of bobcat observations from PS or HS were considered occupied. Townships for which presence and unknown status of bobcats were declared by both indices were identified and totaled. PS and HS were combined to create a final distribution map depicting all townships in which bobcats were observed. Because the distribution of HS effort within each township was unknown, and because lack of PS for a given township could have been due to lack of reporting rather than lack of bobcats, bobcat absence was not presumed for any township. However, townships with high effort and no bobcat observations were identified to provide a sense of where bobcats were most likely to be absent or scarce.

Comparing Indices of Relative Abundance

For PS, HS, and CS, indices of relative abundance were created by dividing the respective parameters for abundance by effort. Relative abundance from the MHS was taken as the land-area HSI mean of each WMU, under an assumption of direct correlation between bobcat abundance and habitat suitability. An index value of relative abundance from PS, HS, and MHS was calculated for each WMU.

Spearman's rank correlation among PS, HS, and MHS indices was determined in a pairwise fashion by WMU. Among PS and HS indices, WMU that received a small amount of sampling effort were expected to have had a smaller percentage of their area sampled, and thus produce index values less representative of the entire WMU. To determine which WMU were not adequately sampled, and to reduce the influences of confounding variables due to small sample sizes, WMU were only included in analyses if they received enough sampling effort for 5 bobcat observations at the average statewide rate. For PS and HS indices, average statewide rates were determined by dividing the summation of the effort parameter from all WMUs by that of the abundance parameter (e.g., total hunter outings divided by total outings with bobcat observed, statewide).

Because CS produced limited data and did not occur statewide, Pearson correlation coefficients were calculated between the CS index and the PS, HS, and MHS indices using the three study areas as sample units and records from 2013 only. For this analysis, data from all indices were restricted to townships that contained camera stations. Logistic regression was used to compare the CS and MHS indices at a finer resolution. Mean HSI value of all land area within a 1-km radius about each camera station was assessed as a predictor variable for bobcat detection. A radius of 1 km was selected as a compromise such that values from the MHS would be representative of the camera's immediate surroundings while allowing for some spatial uncertainty (i.e., discrepancy between actual location of camera and location defined by reported coordinates; Appendix D). The maximum uncertainty among camera locations where bobcats were detected was 800 m. Because the number of camera stations that detected bobcats limited the statistical power of the analysis, 800 m was the maximum allowable positional uncertainty for inclusion of location records. The probability of a camera station detecting a bobcat was expected to increase with mean MHS value. All statistical analyses in this study were performed in JMP 11.0 (SAS Institute, Cary, NC).

CHAPTER 3

RESULTS

I received 938 public sightings (PS) from April 2009 through March 2014. Of these, 886 were successfully screened from 187 townships, and 819 were assigned to 23 WMU. NHFG received 83,406 records of hunter outings through hunter surveys (HS) over the 5-year period. Of these 82,796 were successfully screened from 173 townships, and 80,146 were assigned to 24 WMUs.

Of >77 prospective citizen scientists who reserved survey units or expressed interest in participating, 55 sent photographs from 180 completed camera surveys. Of these, 13 surveys were excluded from analyses due to incorrect camera positioning, camera malfunction, and unaccounted for images missing from photograph sequences (see Appendix C). The remaining 167 surveys collectively produced 2264 trap nights (TN; $\bar{x} \approx 13.6$). When volunteers failed to report deployment and collection dates, I used date stamps on the first and last photographs of the attractant setup to calculate TN. When there was a photo of a volunteer setting up or removing attractants with a date stamp before or after the respective reported date, I used the date stamp to calculate TN. If a volunteer failed to report one or both dates and their photos lacked date stamps, I assumed a survey duration of 14 days. I disregarded all photos and TN generated after Dec 16th. Camera surveys that detected bobcat (n=14, 8%) produced a total of 15 detections (Fig. 3-1), yielding an overall detection rate of 0.66 detections per 100 TN. Study areas included 48 townships and bobcats were detected in 11 of these.

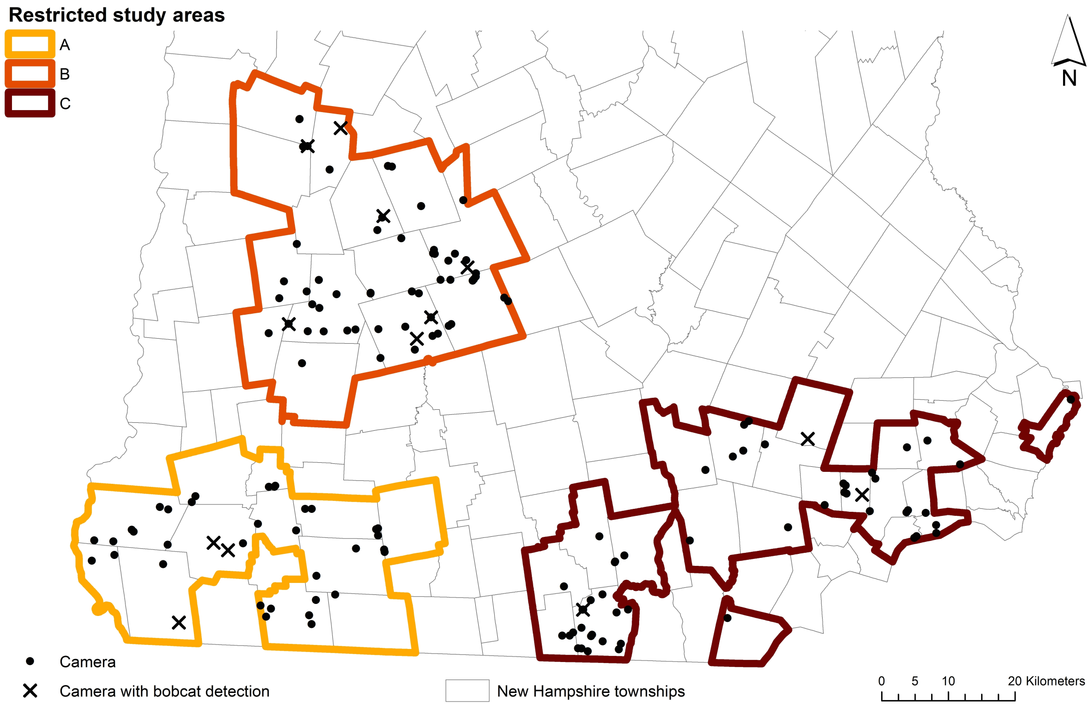


Figure 3-1. Camera locations (n=164) including those with bobcat detections (n=13) and restricted study area boundaries for camera surveys conducted by citizen scientists in November and December of 2013. Coordinates were not received for one camera station in each study area.

Statewide Distribution of Bobcats

Collectively, PS and HS detected bobcats in 211 of New Hampshire's 259 townships (Fig. 3-2). Although there was substantial overlap among bobcat detection from the two sources, PS seemed to provide more information on the statewide distribution of bobcats. Specifically, PS occurred in 187 townships and 86% of the townships where hunters reported bobcats, while HS detected bobcats in 173 townships and 79% of the townships where PS occurred. However, PS and HS complement one another. PS occurred in 24 southeastern townships, and 15 closer to the White Mountains, that HS failed to detect bobcats in. HS detected bobcats in 13 northern and 12 southern townships that PS failed to detect bobcats in. There was an obvious lack of bobcat detections by both indices in central New Hampshire and in several northern and southeastern townships.

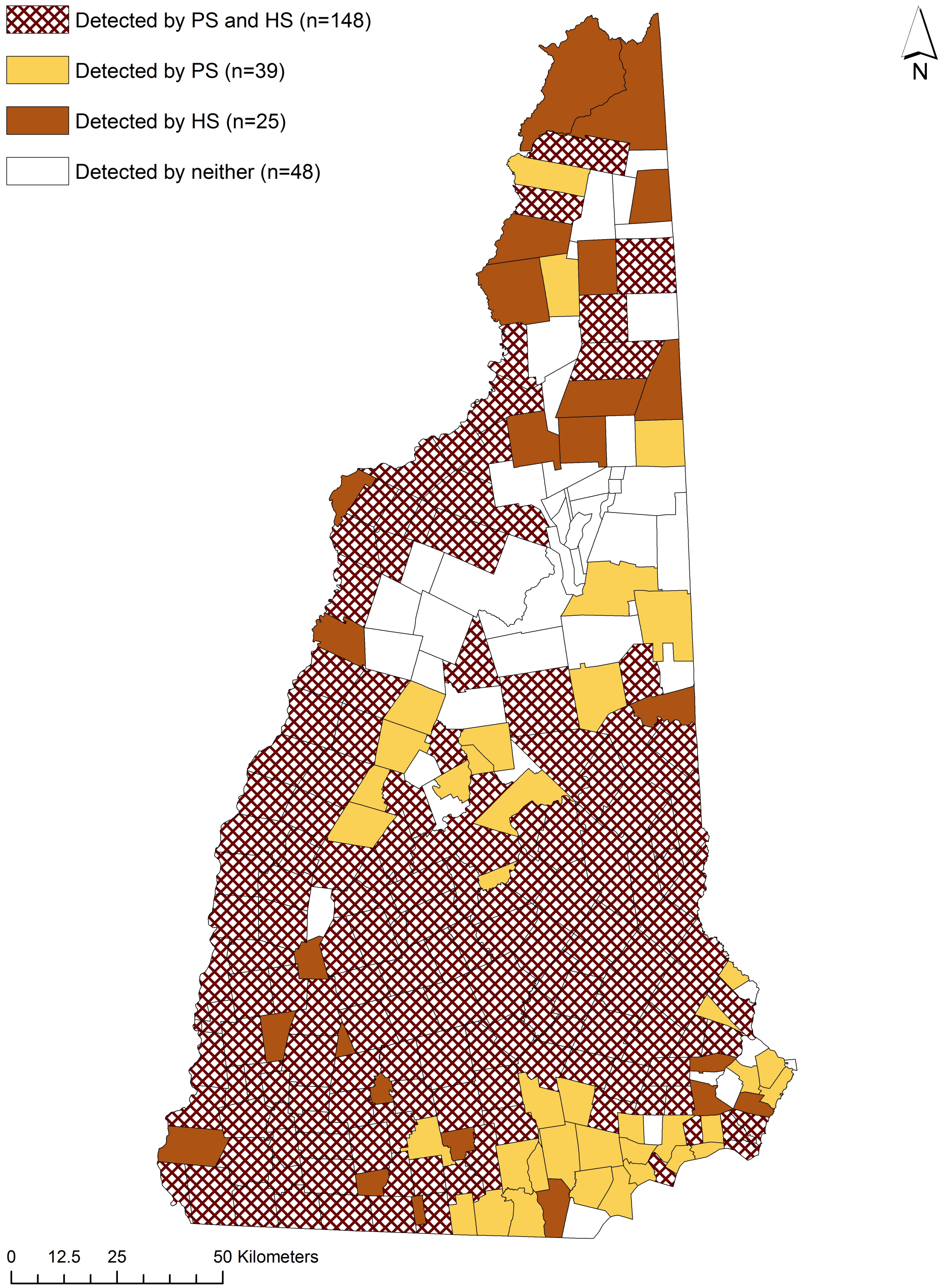


Figure 3-2. Distribution of bobcats in New Hampshire based on public sightings (PS) and hunter surveys (HS) that occurred from April 2009 through March 2014. Sample units are townships. Township of Pittsburg (northernmost township) was divided into two units because of large size. Townships with bobcat detected by PS and HS, PS only, HS only, and neither PS nor HS are shaded accordingly. Number of townships in each category are indicated.

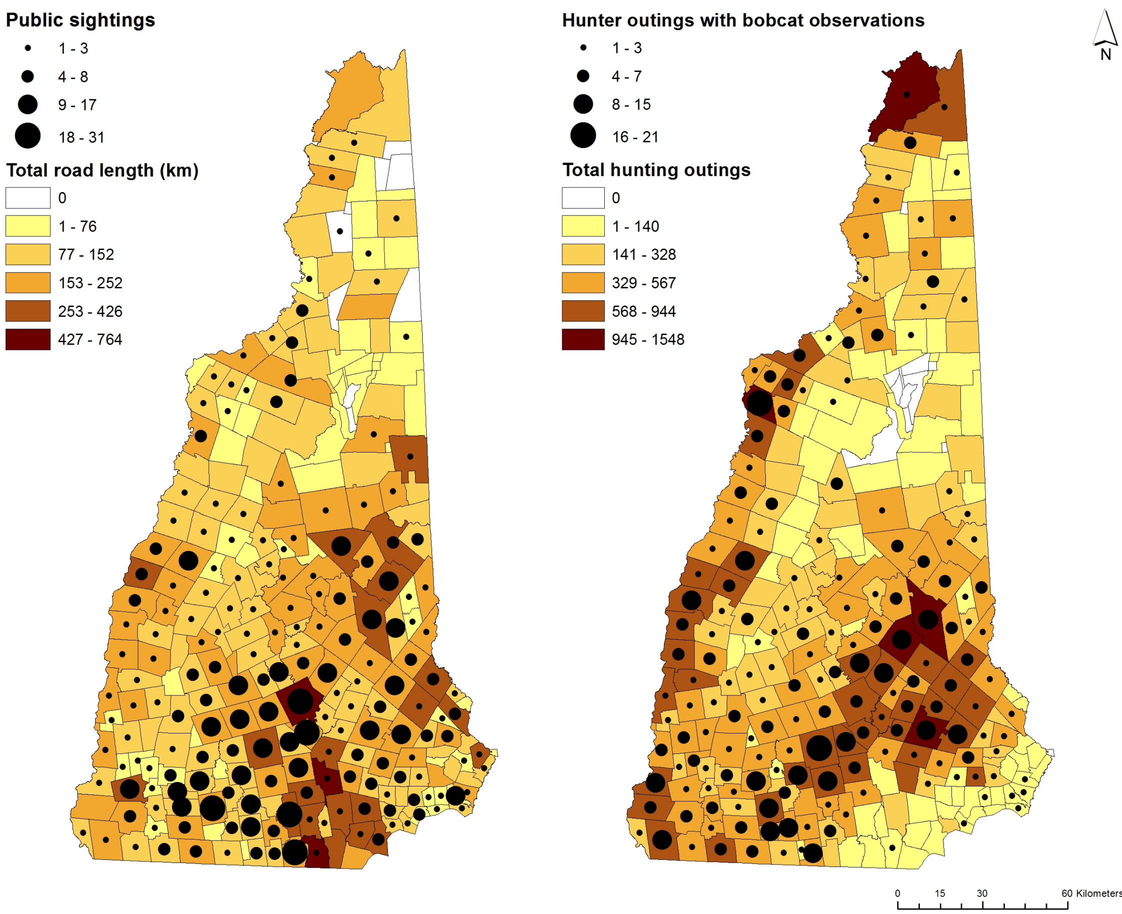


Figure 3-3. Left: number of public sightings overlaid on total road length (km) for each New Hampshire township. Right: number of hunter outings with bobcat observations overlaid on total number of hunter outings for each New Hampshire township. Five categories for effort ≥1 (total road length, total hunter outings), and four categories for detection (public sightings, hunter outings with bobcat observations) were determined by natural breaks.

Overlay of bobcat observations on effort for PS and HS revealed that most townships without bobcat observations also had low effort (Fig. 3-3). For PS, the exceptions to this were the western half of Pittsburgh, two townships in the vicinity of the White Mountains, and four southern townships that had >152 km of road but no sightings. All but one township (Auburn) with >328 hunter outings had bobcat observations.

Relative Abundance of Bobcats

Statewide, PS were received at a rate of 1 per 41.6 km of road over the five-year period (based on 819 sightings assigned to WMUs). PS values for WMU A1, C1, D2E, and E1 were not calculated because these each had less than 208 km of road (i.e., amount for five sightings at statewide rate). Index values of remaining WMUs ranged from 0.3 to 5.4 sightings per 100 km of road ($\bar{x}$ =1.9, s =1.2). Among HS, outings with bobcat observations (O_B) occurred at a statewide rate of 1 per 122 outings over the five-year period (based on 80,146 outings assigned to WMUs). HS values for WMU D2E, E1, E2, and E3 were not calculated because fewer than 610 outings were logged (i.e., amount for five O_B at statewide rate). Index values of remaining WMUs ranged from 1.4 to 12.0 O_B per 1000 outings ($\bar{x}$ =7.7, s =3.3). The model of bobcat habitat suitability (MHS) provided land-area habitat suitability index (HSI) means that ranged from 0.20 to 0.59 ($\bar{x}$ =0.47, s =0.12) for all 24 WMUs.

Considerable variation among relative abundance indices for WMUs was observed (Fig. 3-4). No WMU was placed in the highest relative abundance category by all three indices. However, all indices placed WMUs A2 and B in the lowest category, and J2 was consistently placed in the medium category. WMUs D1, D2W, H2S, J2, and K seemed to be subjects of the most disagreement among indices. In general, WMU M was ranked lower than surrounding WMUs, and northern and central New Hampshire had lower relative abundance than the remainder of the state.

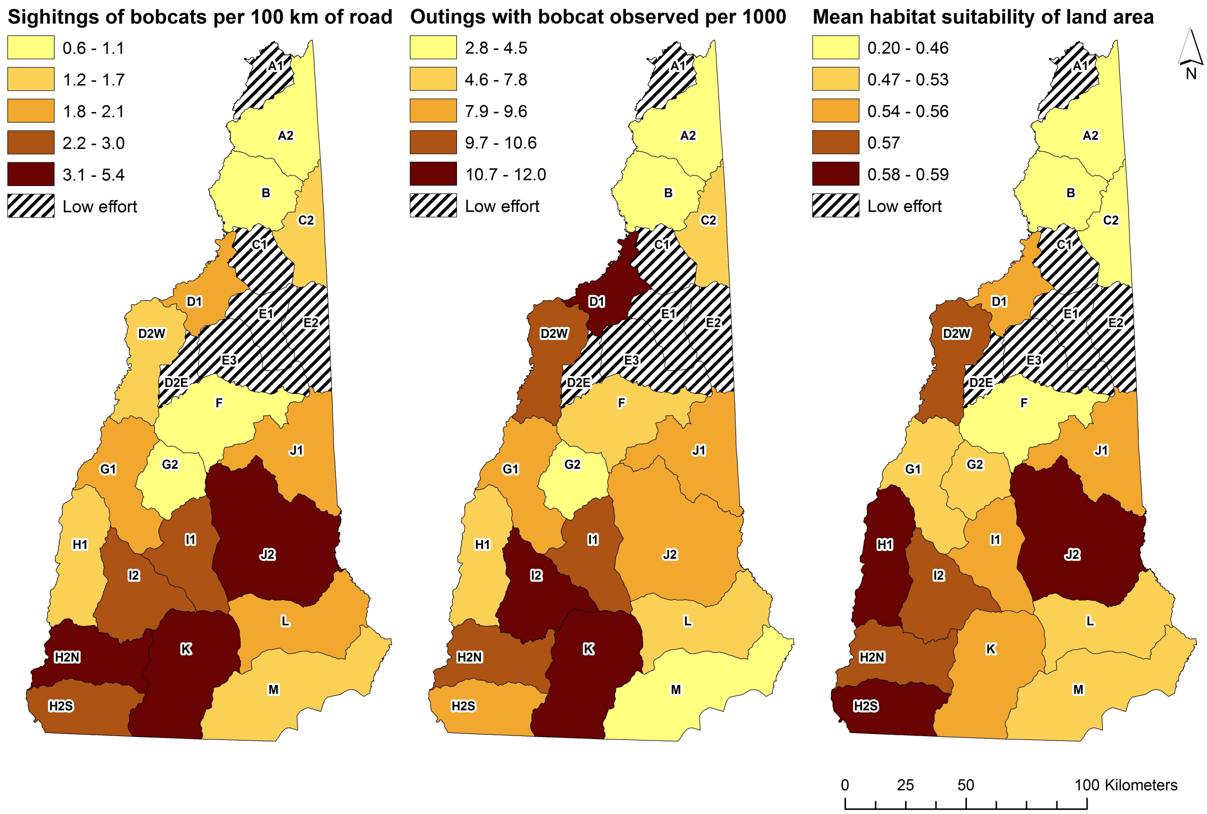


Figure 3-4. Relative abundance of bobcats in New Hampshire based on public sightings (Sightings of bobcats per 100 km of road), hunter surveys (Outings with bobcat observed per 1000 outings), and the model of bobcat habitat suitability (Mean habitat suitability of land area). Five abundance categories were determined using quantiles. WMUs with low total road length or low hunter outings (Low effort) were excluded to facilitate comparison of ranking between indices.

Agreement Among Indices of Relative Abundance

Despite various ranking orders by WMU (Fig. 3-4), all statewide indices of abundance were positively correlated (Fig. 3-5). The PS and MHS indices had the strongest monotonic relationship. WMU K was an obvious outlier (2.8 standard deviations above mean) in the PS index, and was also ranked highest by the HS index. MHS index values were strongly left skewed, indicating a different ranking behavior than PS and HS in which WMUs with high suitability occupied a narrow range of values and those with low suitability were distributed across a wider range.

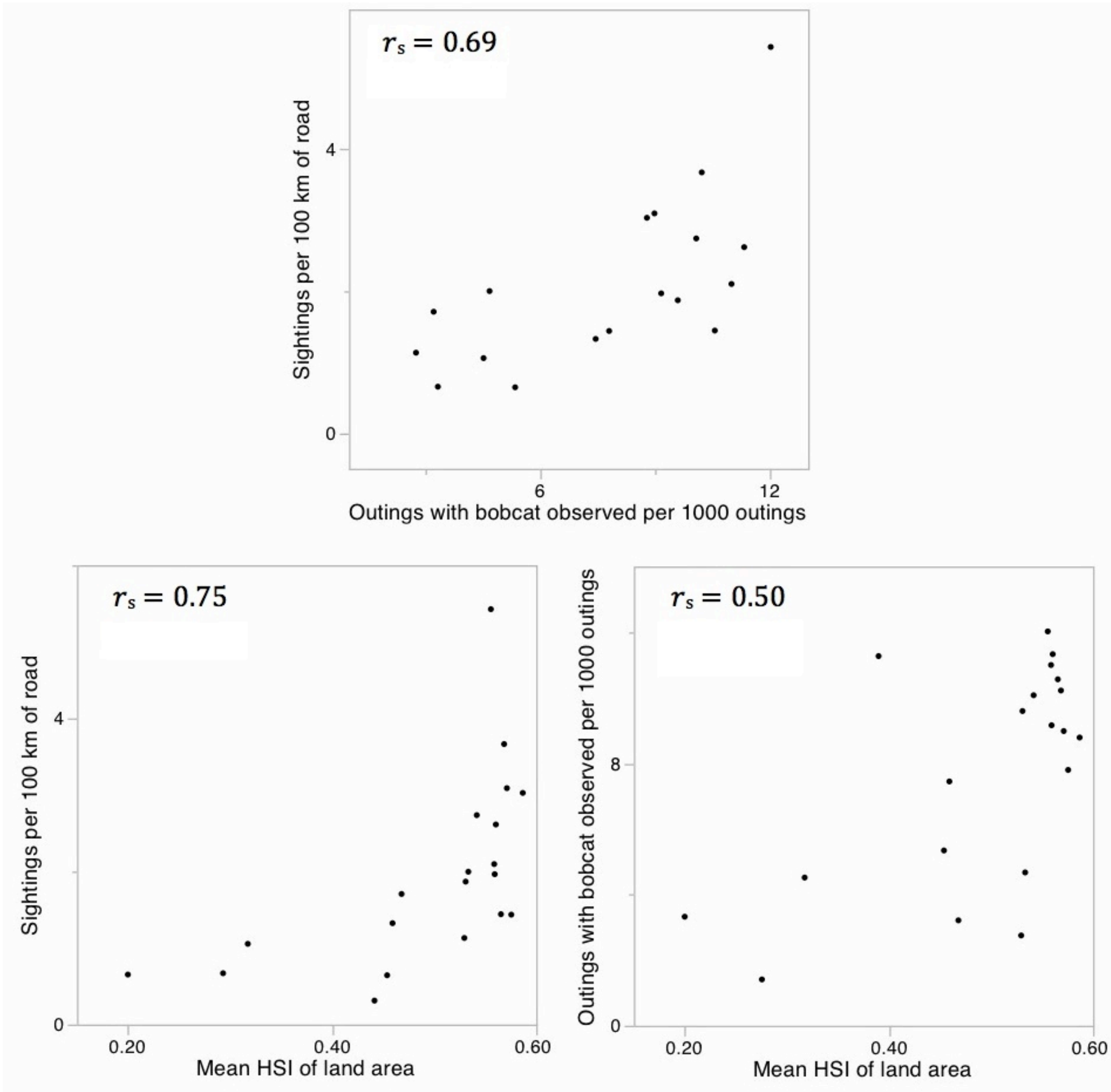


Figure 3-5. Pairwise correlations among public sightings (PS), hunter survey (HS), model of bobcat habitat suitability (MHS) indices using WMUs as spatial units. *P*<0.05 in all cases. For PS and HS, WMUs with low effort have been excluded. PS is expressed as the number of bobcat sightings per 100 km of road. HS is expressed as the number of hunter outings with bobcat observed per 1000 hunter outings. Spearman's-rank (r_s) correlation coefficients are provided in the upper left corner of each scatterplot. MHS is expressed as the mean habitat suitability index value of all raster cells coincident with land area in each WMU.

Although the relative abundances of bobcats determined from camera surveys were as expected based on hunter surveys from 2009 through 2012 (i.e., C=low, A=med, B=high; Fig. 3-6), a different ranking was observed for PS and HS index values within restricted study areas during 2013 and in the MHS index (i.e., C=low, B=med, A=high). Although all indices ranked Study Area C lowest, there was disagreement between CS and all other indices regarding the relative abundance of bobcats in study area A versus B. Despite this discrepancy, correlation coefficients for pairwise comparisons between indices of abundance in restricted study areas were positive and ranged from 0.45 to 1.00 (Table 3-1). CS were weakly correlated with HS and PS, and moderately correlated with the MHS.

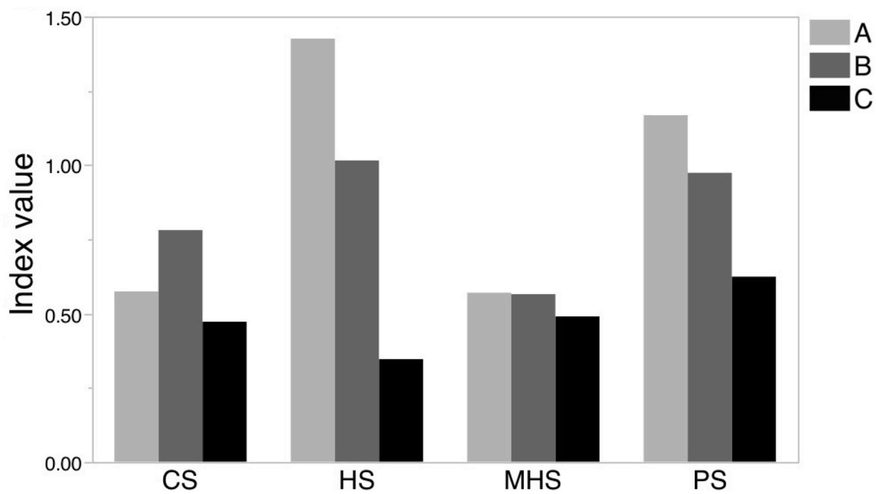


Figure 3-6. Relative abundance index values in study areas A, B, and C in 2013 for camera surveys (CS; bobcat detections per 100 trap nights), public sightings (PS; number of sightings per 100 km of road), hunter surveys (HS; number of hunter outings with bobcat observed per 100 hunter outings), and a model of bobcat habitat suitability (MHS; mean suitability value of all land area).

Logistic regression testing land-area MHS means of camera station locations as a predictor for bobcat presence was not statistically significant (*P*=0.48), but produced a model displaying increasing probability of bobcat detection with increasing land-area HSI means (Fig. 3-7). The HSI mean for camera station locations with detections (0.59) was barely higher than the HSI mean for those without (0.57). The range of MHS means for locations with bobcat detections (0.52 to 0.71) was restricted to higher HSI means, whereas the range for locations without detections included lower HSI means (0.21 to 0.69). Non-significance is likely attributable to a low sample size of camera locations with bobcat detections (n=13).

Table 3-1. Matrix of Pearson's correlation coefficients for pairwise comparisons of index values from camera surveys (CS), hunter surveys (HS), public sightings (PS), and a model of bobcat habitat suitability (MHS). Restricted study areas were used as sample units; refer to Fig. 3-6 for index values.

	CS	HS	PS	MHS
CS	1.00	0.45	0.47	0.72
HS	0.45	1.00	1.00	0.95
PS	0.47	1.00	1.00	0.95
MHS	0.72	0.95	0.95	1.00

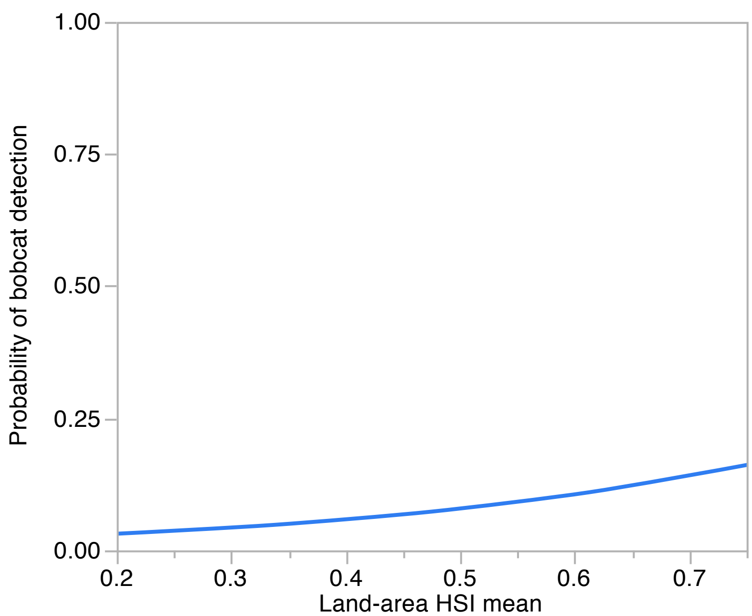


Figure 3-7. Results of logistic regression assessing land-area habitat suitability index (HSI) means within 1 km of camera stations as a predictor for the probability of a camera station detecting a bobcat. *P*=0.48.

CHAPTER 4

DISCUSSION

Public sightings (PS) and hunter surveys (HS) revealed that bobcats were widely distributed throughout New Hampshire (Fig. 3-2). Although regions in the White Mountains and northern townships likely lacked the amount of roads and hunter surveys needed to detect bobcats (Fig. 3-3), snow depth and winter severity are expected to substantially limit bobcat populations here (Broman et al., 2014; Mautz & Pekins 1989; McCord, 1974). Fox (1990) observed substantially lower population densities for bobcats in northern New York's Adirondack Mountains relative to those in southern New York's Catskill region, where winters were less severe. The presence of lynx (with large feet adapted for snow) in northern New Hampshire indicates harsher environments for bobcats. Recent surveys by Sirén (2014) primarily in New Hampshire's White Mountain National Forest and northern Vermont produced 102 and 19 bobcat detections via track and camera surveys, respectively, including five track observations and two camera detections at high elevations. Track surveys and cameras documented lower detection rates of bobcats at high elevations. Thus, I suspect that a combination of low effort and low bobcat densities were responsible for the failure of PS and HS to detect bobcats in several townships in the White Mountains and northern New Hampshire.

I believe that HS provided a better index of relative abundance than PS. First, HS provided reports of presence and absence that were spatially and temporally coincident with reported measures of effort. For PS, non-detections were not reported and effort was more loosely tied to the parameter for abundance. The PS index was also confounded by variation in the probability that a given observation would be reported. For HS, it is safe to assume that most hunters who reported effort also reported all of their bobcat observations. For PS, I suspect that residents in some regions were more likely to report bobcats than in others. This discrepancy cannot be accounted for without conducting some type of public survey. An additional advantage of HS is that the system is already in place, and hunters are willing to participate in surveys. For PS, effort is needed to solicit observations and maintain interest such that the public is compelled to report observations when they occur.

When considering future monitoring efforts, it is important to note that distribution and relative abundance are determined using the same information. For distribution, locations of observations are logged to determine a geographic range. For relative abundance, locations of observations are logged and totaled by geographic units to represent the relative density of individuals. When assessed at the same spatial resolution (e.g., by township), the two measures differ in that distribution requires only one observation to assert that a township is occupied, whereas relative abundance requires multiple observations and a measure of effort such that the number of individuals may be gauged. If observational effort can be assumed to be constant through space and time, it does not need to be measured. This is hardly the case for PS and HS, as indicated by spatial variation in the density of roads and hunter surveys (Fig. 3-3). Knowledge of relative abundance is needed to thoroughly assess the status of bobcats over time. If only enough records were collected to assert distribution, shifts in density could go undetected, while the area of occupancy would appear relatively unchanged at the resolution of township. However, if distribution were described at a spatial resolution of home range-size or finer, the proportion area occupied may provide a good index of relative abundance for any spatial unit larger than several home ranges (MacKenzie and Royle 2005).

Indices and Confounding Variables

Despite cautions against use of indices to monitor wildlife populations (MacKenzie 2006, O'Brien 2011), they are prominently employed by wildlife management agencies (e.g., for bobcats, see Roberts and Crimmins 2010) and in research-oriented studies (Conn et al. 2004, Evangelista et al. 2009, Kindberg et al. 2009, Bengsen et al. 2011, Letnic et al. 2011). Thus, increased understanding of the problems associated with indices is needed (Sollmann et al. 2013). Studies that rely on indices of relative abundance should acknowledge these problems (Linde et al. 2011, Cooper et al. 2012). To infer changes in abundance from an index, variation in the value of the index must be caused by variation in animal abundance. No factors other than animal abundance (i.e., confounding variables), neither singly nor in concert, should overpower variation in animal abundance as a driver of the index. An important, but unmeasured factor influencing the PS, HS, and CS indices was the detection probability of bobcats (Conn et al. 2004, MacKenzie 2006).

The probability that a bobcat observation will occur is influenced by the nature and amount of detection effort, by the behavior and abundance of bobcats, and by the environmental setting. Factors such as hunting techniques, number of potential observers, and time spent with bobcat habitat in view likely influence detection effort. Habitat preferences of bobcats and wariness of human activities are factors expected to influence bobcat detectability. Factors such as vegetation density, terrain ruggedness, amount of human development, and climate describe the environmental setting. It is difficult to determine the ultimate influence that these factors have on detection probability because they also influence the nature of and amount of detection effort and the behavior and abundance of bobcats. For example, dense vegetation would make bobcats difficult to observe, but detection probability may be higher if bobcats frequently visited areas with dense vegetation to prey on rabbits living there.

PS and HS indices in this study each incorporated one effort-related parameter. If effective, the simplicity of this approach may make it a more efficient management tool than indices that may achieve higher accuracy by accounting for several variables simultaneously (see Appendix F, which combines the number of hunter outings and hunter hours in one index). However, investigating the influence of other variables on detection probability could reveal alternative parameters that allow for more accurate indices no more complex than those used in this study. Further, such investigations could lead to the development of numerous indices that managers could select from, with more complex indices providing more accurate relative abundance estimates at the expense of more data collection and processing.

For PS, road length was used to indicate effort. Strong linear correlation between total road length and human population among 24 WMUs (r =0.94, P<0.05) indicated an index based on either parameter would have revealed similar trends in relative abundance. However, it is worth noting that WMU L had 3456 km of road and a human population of 216 thousand residents, while WMU K had a similar total road length (3409 km) but about 77 thousand fewer human residents (i.e., potential bobcat observers). This likely had a substantial influence on the number of reported bobcat observations. An index that accounted for both human population and total road length would likely yield more accurate estimates of relative abundance. In addition, factors related to housing density and bobcat observations reported by non-residents have not been considered, but likely influence this index as well.

The accuracy with which the PS index described relative abundance depended on similar distribution of survey effort in each WMU. Although road length and total human population were strongly correlated among WMU, factors such as traffic volume and total length of road traversing suitable habitat were not accounted for. Clearly, a road that is infrequently used, or is located in a city, would have a lower potential for producing an observation than a road with moderate traffic bisecting bobcat habitat.

For HS, number of hunter outings indicated how many surveys were conducted in a given study area. Total hunter outings and total hunter hours for 24 WMUs were linearly correlated extremely well ($r = 0.997$, $P < 0.05$). However, in theory, the duration of surveys varies independently of the number of outings. Discrepancy would occur if there were WMUs with a ratio of total hours to total outings that differed substantially from the mean. If this were the case, both of these factors should be accounted for in the index. A WMU that consistently received longer hunting outings would have received more effort than one with the same number of shorter outings (Appendix F). In this study, hours and outings were so closely correlated that this discrepancy was presumed negligible.

In an exploratory investigation that occurred after the primary analyses of this study, PS and HS indices that each incorporated two parameters for effort were more strongly correlated than PS and HS indices using one parameter for effort. I repeated the analysis comparing *Sightings per 100 km of road* and *Outings with bobcat observed per 1000 outings* exactly (Fig. 3-5), but used the following as a PS-based index:

$$\frac{S^2}{RP}$$

where S is the total number of public sightings, R is total road length, and P is total human population. The following was used as a HS-based index:

$$\frac{{O_B}^2}{OH}$$

where O_B is the number of hunter outings with bobcat observed, O is the number of hunter outings, and H is the total number of hunter hours. The numerators of each formula were squared to counteract the influence of two parameters in the denominator. Using the new formulas, the Spearman's correlation coefficient increased from 0.69 to 0.81, indicating that PS and HS indices ranked WMUs in a more similar order. Further research is needed to determine if indices incorporating multiple parameters for effort are better indicators of the relative abundance of bobcats, or if other factors were responsible for my observation of improved agreement in this case.

In addition to the nature and amount of effort from citizen observers, the probability that an observation will occur depends on the detectability of the species (Sollmann et al. 2013). Detectability is influenced by variables that describe habitat and the behavior and distribution of bobcats. For HS, bobcats may be more detectable in regions where they frequent open woodlands or patrol field edges and less detectable in regions where they occupy denser vegetation. For PS, detectability may be lower in regions where bobcats avoid roads and human developments relative to those where bobcats frequently cross roads and enter backyards (perhaps to prey on gray squirrels *Sciurus carolinensis* at birdfeeders; Broman et al., 2014).

Other than the probability of a bobcat observation occurring, the number of PS is influenced by the probability that a given observation will be reported (report rate). Because HS documented presence and absence, this confounding variable was avoided. I expect the report rate of PS was higher in areas recently colonized by bobcats and lower in areas where bobcat observations have been occurring for several decades (possibly WMUs D1 and D2W, see Fig. 3-4). So, I believe I observed bias in this index toward areas in southern New Hampshire (WMU K, L, M) where bobcats have recently expanded to (Fig 3-3; Broman et al. 2014).

Public surveys that ask recipients to report presence or absence of bobcats may offer a means of avoiding bias from variation in report rate. Like HS, abundance could be inferred from public surveys as the ratio of surveys with bobcat observations to all returned surveys. However, recipients who observed bobcats would likely be more motivated to respond than those who did not observe bobcats (similar to Barker 1991). To avoid this, public surveys could be generalized and request reports of presence or absence for an array of species (van Strien et al. 2013), similar to hunter survey cards (Appendix E).

An important distinction is that public sightings are only generated when residents incidentally observe bobcats whereas the generation of hunter survey records is presumably uninfluenced by the abundance of bobcats. Including species commonly seen (e.g., bear, deer, turkey, rabbit, squirrel) and offering incentives (e.g., entry into a raffle) for pubic surveys could eliminate this discrepancy and help achieve high survey response rates. Constraining observations to those that occurred within a timeframe and in the citizen scientist's township of residence should allow for detection of gradients in relative abundance across space and time. This approach could also potentially offer a source of absence data for occupancy modeling.

Spatial distribution of survey effort within sampling units was an additional confounding variable for PS, HS, and CS indices. Within a given WMU, PS and HS are not expected to have occurred in the same areas. The vast majority of public sightings occurred along roads and in close proximity to homes (Broman et al. 2014). Hunters likely observed bobcats in larger woodlots on unprotected or privately owned land. If a given WMU had bobcats that primarily resided in close proximity to residential areas, but all hunting occurred in an area with few bobcats, the PS index would be higher. If another WMU had hunting that occurred in an area rich with bobcats, and bobcats in that WMU avoided development, the HS index would be higher. PS and HS indices complement each other in this way, and disagreement between them may indicate the distribution or habitat selection preferences of bobcats in the sampled area.

Multiple observations of the same individual also cause issues for indices. Ideally, an index of relative abundance should reflect the number of individuals within each region of the study area (O'Brien 2011). Among PS, I received multiple sightings from the same observers in the same location over multiple months and years. I suspect that most of these were cases of the same bobcat visiting the same backyard.

Even with numerous confounding variables at work, PS, HS, CS, and MHS were all positively correlated (Fig. 3-5, Table 3-1). Correlation between two indices is often interpreted as an indication that they successfully describe abundance of the species in question (e.g., Rolandsen et al. 2011). However, disagreements still existed. My study supports others that rely on hunter survey indices to gauge density (Linde et al. 2011, Rolandsen et al. 2011) by demonstrating positive correlation with other indices. However, camera survey efforts lacked the rigor needed to directly estimate bobcat density and only offered weak validation of other indices. Based on their continued use, I recommend further efforts to refine indices by concurrent monitoring with capture-recapture or minimum counts of individuals and assessment of how well discrepancy is explained by confounding variables. This may involve development of methods for parameterizing confounding variables such as report rate, hunting techniques, or habitat type, which could be a challenging endeavor. I suspect these investigations would find it appropriate to introduce several variables into index equations (e.g., Appendix F), creating more complex and accurate models for the relative abundance of bobcats. For example, a more accurate PS index may be constructed by incorporating total road length, human population, an estimate of report rate, and traffic volume into a single index.

Considerations for Occupancy Modeling

Although occupancy modeling has become a popular method for inferring carnivore distribution (e.g., O'Connell et al., 2006; Rich et al., 2013), it was not an appropriate approach given the data available and is unlikely to be used for monitoring bobcats in New Hampshire in the immediate future. PS did not produce a viable dataset for this approach due to a lack of non-detection information. Spatial variation in the ratio of reported observations to non-reported observations likely existed, and would have invalidated models. CS directly gauged a parameter for effort (trap nights). However, over the three sampling periods, the average probability of a camera station-survey detecting a bobcat was 0.08. Mackenzie and Royle (2005) recommended >3 surveys per sampling unit when detection probability is below 0.5. Aggregating camera survey units to achieve higher detection probabilities would have yielded a spatial resolution too coarse to provide useful information (see Appendix B). Thus, some combination of greater survey effort from citizen scientists (e.g., increasing numbers of cameras or survey periods) and higher detection probabilities (e.g., more effective attractants, strategic camera placement, optimizing season for bobcat detection) would be needed to produce sound occupancy models. Clare et al. (2014) succeeded in using camera traps and occupancy modeling to predict bobcat distribution, but experienced much higher detection rates (3.8/100 TN compared to 0.66/100 TN in New Hampshire). For HS, the average detection probability among surveyed townships during any one hunting season was 0.37 (*number of townships in which bobcats were observed for each year summed across all five years* and divided by *total number of townships surveyed each year and summed across all five years*), and in this case there were 5 seasons. This makes the HS dataset most suitable for occupancy analysis; however, issues arise because the distribution of survey effort is unknown within townships and is non-random between townships.

The major utility of an occupancy model for the distribution of bobcats in New Hampshire would be to estimate the probability of occupancy, which is also interpretable as proportion of area occupied (MacKenzie 2006), for areas that were not sufficiently surveyed. But, the non-random distribution of hunter effort among townships prevents a probabilistic sampling scheme. In which case, there would be no basis for use of covariates to estimate probability of occupancy for sites that were not sampled (MacKenzie 2006). This is because covariates that influence bobcats (e.g., mean snow depth, deer density, distance from roads, elevation) also influence the distribution of hunter effort, and likely have values beyond which hunting did not occur. Prediction of occupancy using covariate values beyond those for which their relationship to bobcat occupancy is known (i.e., extrapolation) would yield an unreliable model. Further, the distribution of hunter effort within townships is unknown, and its relationship to potential covariates could vary geographically or temporally. To make HS most conducive to occupancy modeling, hunters would need to focus efforts on randomly selected survey units, which is unlikely to occur.

Improving Calibration of Indices

Despite enthusiastic response from citizen scientists and numerous camera surveys, the utility of this index was hampered by low detection rates. Detection rate of bobcats across all study areas was 0.7 detection events per 100 TN, which was lower than those observed for unbaited camera surveys in Wisconsin (3.8; Clare 2013) and Virginia (1.5; Kelly and Holub 2008). Use of attractants was expected to increase detection rate (du Preez et al. 2014). The percentage of camera stations that detected bobcats (8%) was higher than observed among stations in adjacent southern Vermont with similar attractants (1%; Moruzzi et al. 2002). Use of cameras triggered by pressure-plates was likely responsible for lower rates in Vermont. Detection rates are higher for cameras with passive infrared triggers (Swann et al. 2011) used by volunteers in the New Hampshire study.

Photos collected by volunteers in New Hampshire indicated that bobcats were enticed by our attractants (Fig. 4-1). Further, detections rates (i.e., detection events per 100 TN) among coyote (*Canis lantrans*; 1.06) and gray fox (*Urocyon cinereoargenteus*; 1.55) were higher than those observed among unbaited stations in Virginia (coyote, 1.01; fox, 0.56; Kelly and Holub 2008). Percentage of camera stations that detected these species and fisher (*Martes pennanti*) were also higher in New Hampshire (coyote, 13%; fox, 14%; fisher, 23%) than in Vermont (coyote, 6%; fox 1%; fisher 16%; Moruzzi et al. 2002). Detection rates of bobcats in New Hampshire and Vermont may be low in comparison to those in other parts of the specie's range. This could be due to the animal's behavior, density, or habitat in New Hampshire.

By enlisting citizen scientists who owned trail cameras, I achieved 15 detections with the only expenses being attractants and time spent coordinating the project and volunteers (although 6 university-owned cameras were loaned to volunteers). Coordinating volunteers by email was extremely time consuming. Although an automated, or web-based data collection system would likely be more efficient, interactive training sessions and direct communications were often enjoyable and educational for both the volunteers and biologists involved. Educational outcome may not have been as high if automated training sessions (e.g., online videos) and data collection were used (Bonney et al. 2009). Direct interaction with researchers may boost volunteer motivation and perhaps the rigor and data quality achieved by the citizen scientists as well.

Figure 4-1. Bobcats investigating catnip oil (left), head rubbing near Caven's gusto lure (center; Minnesota Trapline Products, Pennock, MN), and rolling on ground below catnip oil. Photos captured by Debra Dunlop and Maria Colby (left), Andy Fisher (center), and Susan Parmenter (right) during camera surveys conducted in southern New Hampshire from November to December 2013.

I suggest that future camera surveys in New England assess trap rates of bobcats when no attractants are used, as another means of minimizing cost. The attractants used in this study were effective but costly. There were a few prospective volunteers who did not participate because they were unable to attend training sessions and I could not get attractant kits to them. Longer sampling periods and strategic placement of cameras (e.g., along linear features) could allow for functional detection rates without attractants (Clare et al. 2014). Placement along linear features could also minimize occurrences of bobcats moving across the field of view faster than camera's trigger delay (Bengsen et al. 2011). If detection rates without attractants are too low, low-cost attractants (e.g., cat food, sardines) may allow for an increase in the number of bobcats detected by accommodating more citizen scientists, while lowering material costs spent by researchers.

Further, I experienced many concerns over the integrity of data reported by volunteers. Volunteers removed photos of themselves setting up attractants, and photos that did not contain wildlife, despite requests to submit all photographs. In a few instances, volunteers modified their attractant setup despite receipt of a protocol that stressed the importance of standardization among all camera stations (Appendix C). Concerns over data integrity stemmed largely from contradictory data. For example, volunteers reported camera coordinates that were not within the reported survey unit (Appendix B) and camera deployment and collection dates that did not match date stamps on photographs documenting attractant setup and breakdown. I did a considerable amount of work to obtain correct data from volunteers when I was able to identify contradictions, and to obtain data that volunteers failed to report upon first request.

As a potential alternative to camera surveys, it may be possible to generate minimum counts of individuals through genetic analysis of bobcat scat. Kindberg et al. (2009) found a strong relationship between an index based on hunter observations of brown bears and minimum counts of individuals from DNA in scats. In New Hampshire, hunters, trappers, and naturalists who already track bobcats may be willing to collect scats for this purpose. The major challenge of this approach would be achieving enough sampling effort to thoroughly cover multiple areas that are large enough to reveal differences in bobcat density.

Establishing a Monitoring Protocol

Management decisions are often based on temporal trends in indices of relative abundance. To monitor bobcat populations in New Hampshire using data collection systems currently in place, which are HS, PS, and bobcat-vehicle collisions (VC), there are certain time periods for which index values may be appropriately calculated based on amount of available data. Strong linear correlation (r =0.91, P<0.05) between HS and VC indicate that these two sources of information may be appropriate for assessing annual changes in bobcat numbers statewide (Fig. 4-2). However, annual rates calculated here are based on an uneven spatial distribution of effort (see Fig. 3-3). This could be avoided by randomly sampling hunter outings at a constant density from each WMU or township. Of course, some WMUs and townships would have to be excluded due to lack of hunter outings, and these areas would not be represented in annual trends.

Although the distribution of hunter outings within townships is not controlled or known, areas where they do not occur may be identified by assessing the geography of land cover types and boundaries of various recognized natural areas that may or may not permit hunting (e.g., wildlife management areas, state parks, land trusts). Total land area for regions where hunting may occur in each township could then be calculated, and used to determine the number of hunter outings necessary for thorough coverage. The number of outings to be sampled from each township could be determined using an estimate of the maximum number of bobcats expected to occupy the land area where hunting may occur. This could be estimated based on the possible number of exclusive female home ranges (23.8 km^2; Reed 2013). Then, the number of outings to be sampled could be selected based on the average rate at which hunters have observed bobcats in the WMU containing the township (which may vary substantially from the statewide rate of (1 O_B per 122 outings for some WMUs). Sampling enough hunter outings for each bobcat in the township to be observed multiple times should ensure adequate effort, provided that all hunter outings are not occurring within the same bobcat's home range.

Assessment of trends in some portions of the state may be restricted to longer timeframes due to lower numbers of hunter outings. It seems reasonable to consider index values meaningful only once enough effort for five bobcat observations at the average statewide rate has been logged. A requirement of 610 hunter outings, based on a statewide rate of 1 O_B per 122 outings (calculated from 80,146 outings assigned to WMUs and occurring from 2009-2013), would likely allow for WMUs D2W, H1, H2N, H2S, I1, J2, K, and L to be assessed annually, while the others would require multiple years of data (Table 4-1). When aggregating multiple years of data, it would be important to consider temporal fluctuations in effort, as dynamics in bobcat numbers could influence results. I would suggest randomly sampling a constant number of hunter outings from each year to avoid bias.

Alternatively, data may be summarized from regions larger than WMUs to facilitate use of software such as MONITOR (Gibbs and Ene 2010). In this application multiple samples of hunter outings from each region would be used to generate a variance, allowing the software to estimate the statistical power of a various monitoring schemes. Collection and processing of hunter survey records could then be adjusted to detect a given percent change in the index, based on monitoring needs.

Until the influences of report rate and other confounding variables are understood, I advise that trends in abundance not be based on incidental PS. However, bobcat observations from PS, HS, CS, and VC may be agglomerated by township to describe the known area of occupancy for bobcats to the fullest extent possible. All townships without bobcat observations would have unknown status barring assessment of detection effort. The abundance and complementary nature of PS and HS data make these sources particularly convenient for assessing distribution, and for assessing the distribution and quantity of effort within townships to infer absence. If needed for management purposes, information on the relative abundance and distribution of bobcats in regions where roads and HS are scarce could be obtained by providing some incentive for citizen scientists to conduct CS or HS. Further specifics of the potential monitoring activities I have loosely described depend on specific management objectives, and should be developed under close cooperation between managers and research scientists.

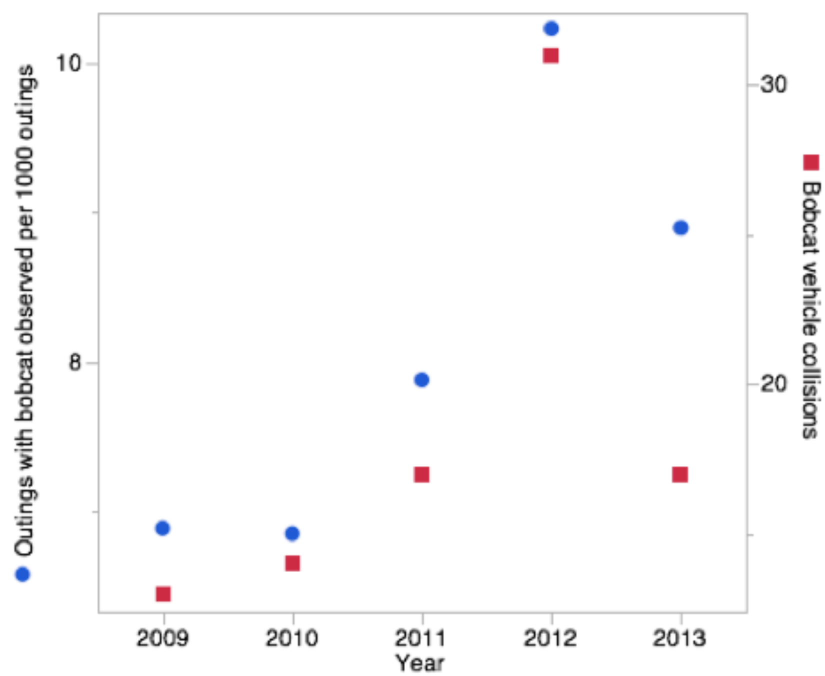


Figure 4-2. Annual statewide trends in the total number of documented bobcat road mortalities and the number of hunter outings with bobcats observed per 1000 hunter outings, from 2009 through 2013. Hunters' observation rates were calculated using 83,357 records of hunter outings collected by NHFG. Records with <0.5 or null hunter hours were excluded (n=49).

Table 4-1. Number of hunter outings logged by WMU from annual hunter surveys in New Hampshire, from 2009 through 2013.

WMU	2009	2010	2011	2012	2013	Total
A1	243	275	243	319	335	1415
A2	457	427	614	485	423	2406
B	410	375	301	316	367	1769
C1	114	133	169	103	191	710
C2	243	164	205	152	176	940
D1	296	308	425	314	199	1542
D2E	4	1	9	25	37	76
D2W	1023	948	847	897	924	4639
E1	37	27	36	30	15	145
E2	52	39	78	42	58	269
E3	25	5	13	23	30	96
F	220	202	265	207	227	1121
G1	513	373	604	772	761	3023
G2	244	220	202	180	242	1088
H1	1293	1270	1197	940	1066	5766
H2N	920	837	907	1024	1009	4697
H2S	734	849	864	940	935	4322
I1	613	625	588	613	637	3076
I2	600	602	537	526	559	2824
J1	607	551	677	609	611	3055
J2	2572	2512	2456	2566	2466	12572
K	2026	2033	2041	1953	2086	10139
L	2063	2035	1972	1996	1985	10051
M	565	542	437	354	2459	4357

APPENDICES

APPENDIX A. IACUC APPROVAL

University *of* New Hampshire

Research Integrity Services, Service Building
51 College Road, Durham, NH 03824-3585
Fax: 603-862-3564

22-Sep-2011

Litvaitis, John A
Natural Resources & The Environment, James Hall
Durham, NH 03824

IACUC #: 110903
Project: Use of Remotely-Triggered Cameras to Monitor Bobcat Populations
Category: C
Approval Date: 21-Sep-2011

The Institutional Animal Care and Use Committee (IACUC) reviewed and approved the protocol submitted for this study under Category C on Page 5 of the Application for Review of Vertebrate Animal Use in Research or Instruction - *the research potentially involves minor short-term pain, discomfort or distress which will be treated with appropriate anesthetics/analgesics or other assessments.*

Approval is granted for a period of three years from the approval date above. Continued approval throughout the three year period is contingent upon completion of annual reports on the use of animals. At the end of the three year approval period you may submit a new application and request for extension to continue this project. Requests for extension must be filed prior to the expiration of the original approval.

Please Note:

1. All cage, pen, or other animal identification records must include your IACUC # listed above.
2. Use of animals in research and instruction is approved contingent upon participation in the UNH Occupational Health Program for persons handling animals. Participation is mandatory for all principal investigators and their affiliated personnel, employees of the University and students alike. A Medical History Questionnaire accompanies this approval; please copy and distribute to all listed project staff who have not completed this form already. Completed questionnaires should be sent to Dr. Gladi Porsche, UNH Health Services.

If you have any questions, please contact me at 862-4629 or Julie Simpson at 862-2003.

For the IACUC,

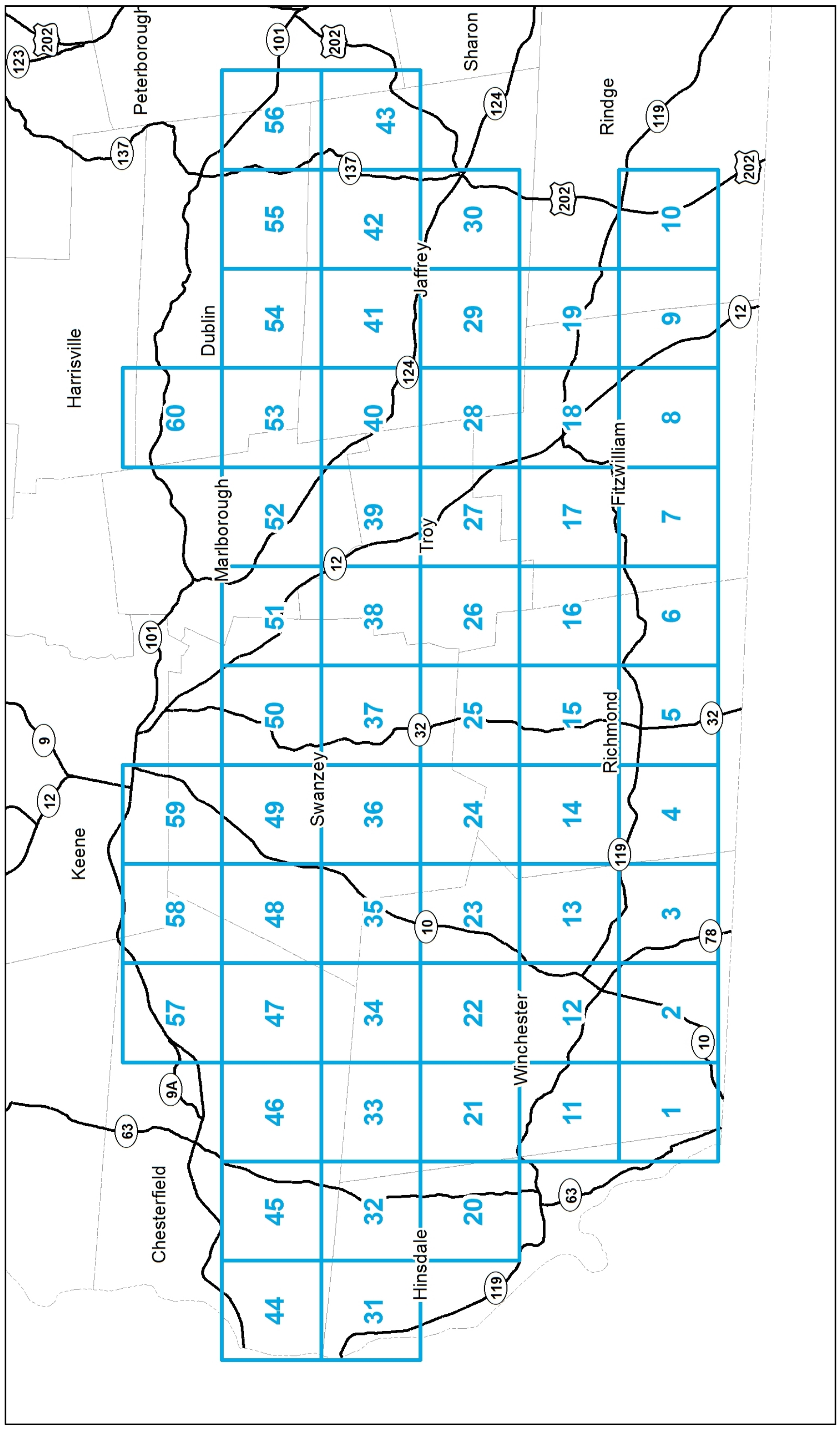
Dean Elder, D.V.M.
Interim Chair

cc: File

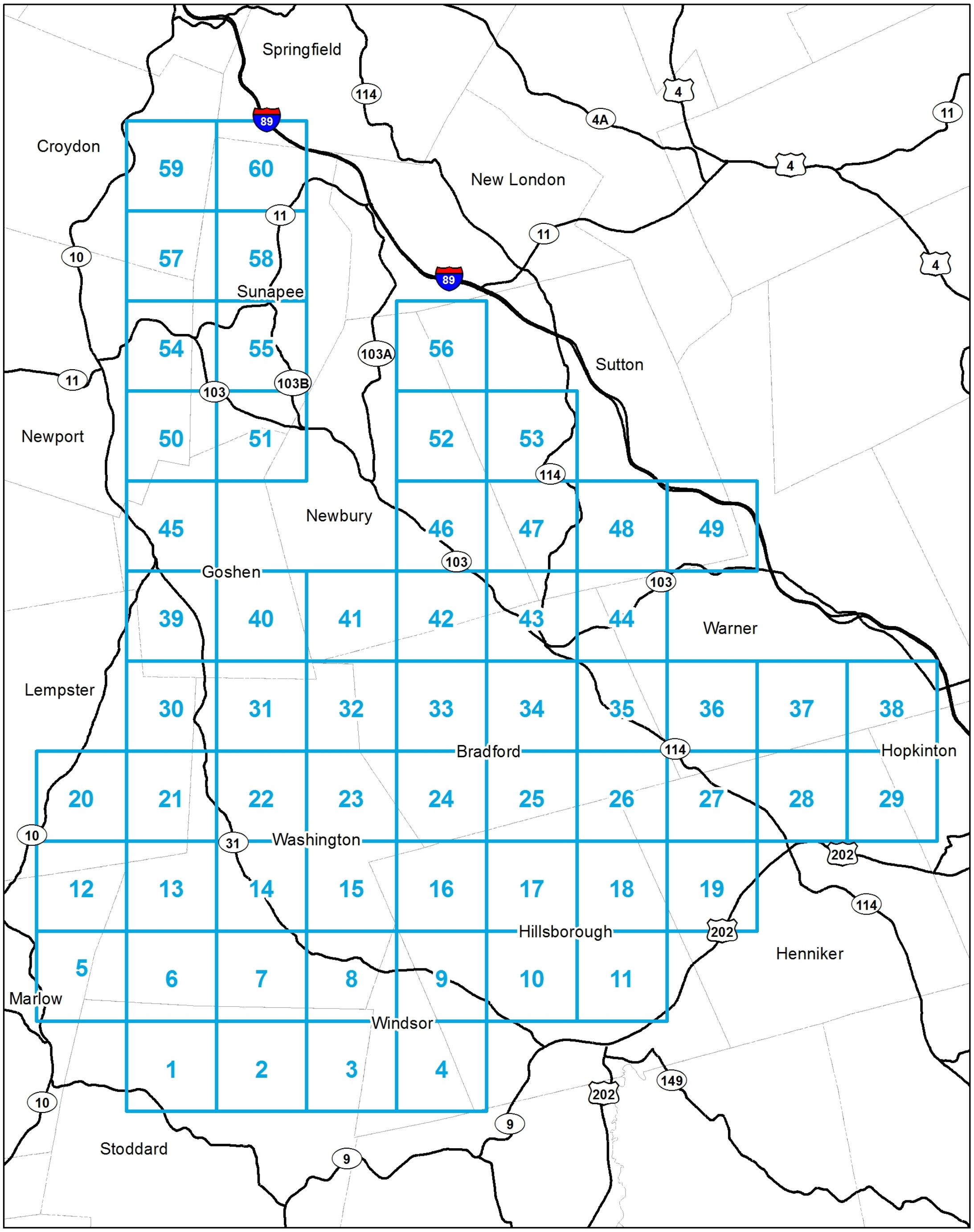
APPENDIX B. CAMERA SURVEY STUDY AREAS

Maps of three study areas for camera surveys conducted by citizen scientists in November and December of 2013. Study areas A, B, and C corresponded to wildlife management units H2S, I2, and M, respectively. Each contained 60 13.3-km^2 survey units.

Study Area A



Study Area B



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Sutton
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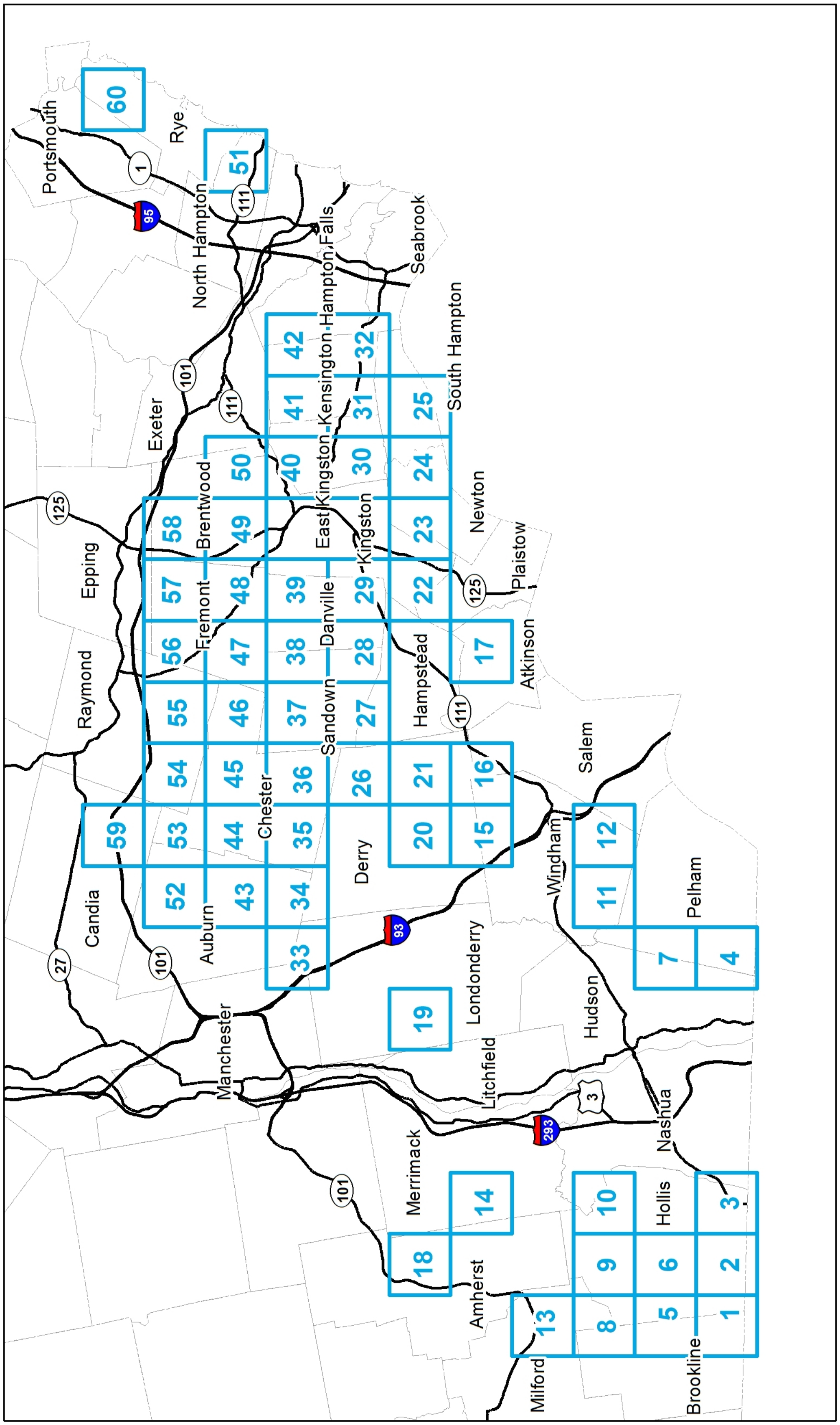
Study Area C



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Hampton Falls
Seabrook
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Kensington
South Hampton
Exeter
Brentwood
East Kingston
Kingston
Newton
Plaistow
Epping
Fremont
Danville
Atkinson
Raymond
Sandown
Hampstead
Chester
Salem
Candia
Auburn
Derry
Windham
Pelham
Londonderry
Hudson
Manchester
Litchfield
Nashua
Merrimack
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Milford
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APPENDIX C. CAMERA SURVEY PROTOCOL

Camera survey protocol provided to all camera survey participants. “Skunk lure” refers to Caven’s “Gusto” Long Distance Call Lure (Minnesota Trapline Products, Pennock, MN)”.

Protocol for the 2013 New Hampshire Bobcat Surveys

University of New Hampshire *in cooperation with* New Hampshire Fish & Game Department
Prepared by Tyler Mahard

Thank you for your assistance with the 2013 New Hampshire Bobcat Surveys. This study is part of an ongoing cooperative project of the New Hampshire Fish & Game Department and the University of New Hampshire. This fall into winter, we will be gaging bobcat abundance through camera surveys in three large regions of New Hampshire. These are the southwest corner (Study Area A), the region west of Concord (Study Area B), and the southeast corner (Study Area C). We will be comparing bobcat abundance estimates from upcoming camera surveys to those from deer hunter surveys, public sightings, and road mortalities for these three regions. This will help us assess the validity of using these indexes to monitor bobcat abundance.

Monitoring any wildlife population informs us of its status and can alert us to potential problems in ecosystems. It also provides us with a better understanding of the function of natural systems and their interactions with human systems. Through better understanding, human activities can be guided in such a way that both people and wildlife can coexist in harmony.

The purpose of this protocol is to ensure standardization of camera and attractant setup among all volunteers participating in the survey. If there were variation in the attractants used at each camera station, these variations could influence the number of bobcat photographs produced. This would limit our ability to interpret the number of bobcat photographs as a reflection of actual bobcat abundance of a particular area.

We will be providing three attractants to be used at camera stations in this study:

1. Skunk lure – Intended to lure bobcats from a long distance
2. Pie tins – Intended to act as a visual stimulus
3. Catnip oil – Intended to encourage bobcats to spend more time in front of the camera

These attractants have been used successfully in other scientific studies of bobcats.

The following pages will explain how to select a location for the camera station and arrange these attractants.

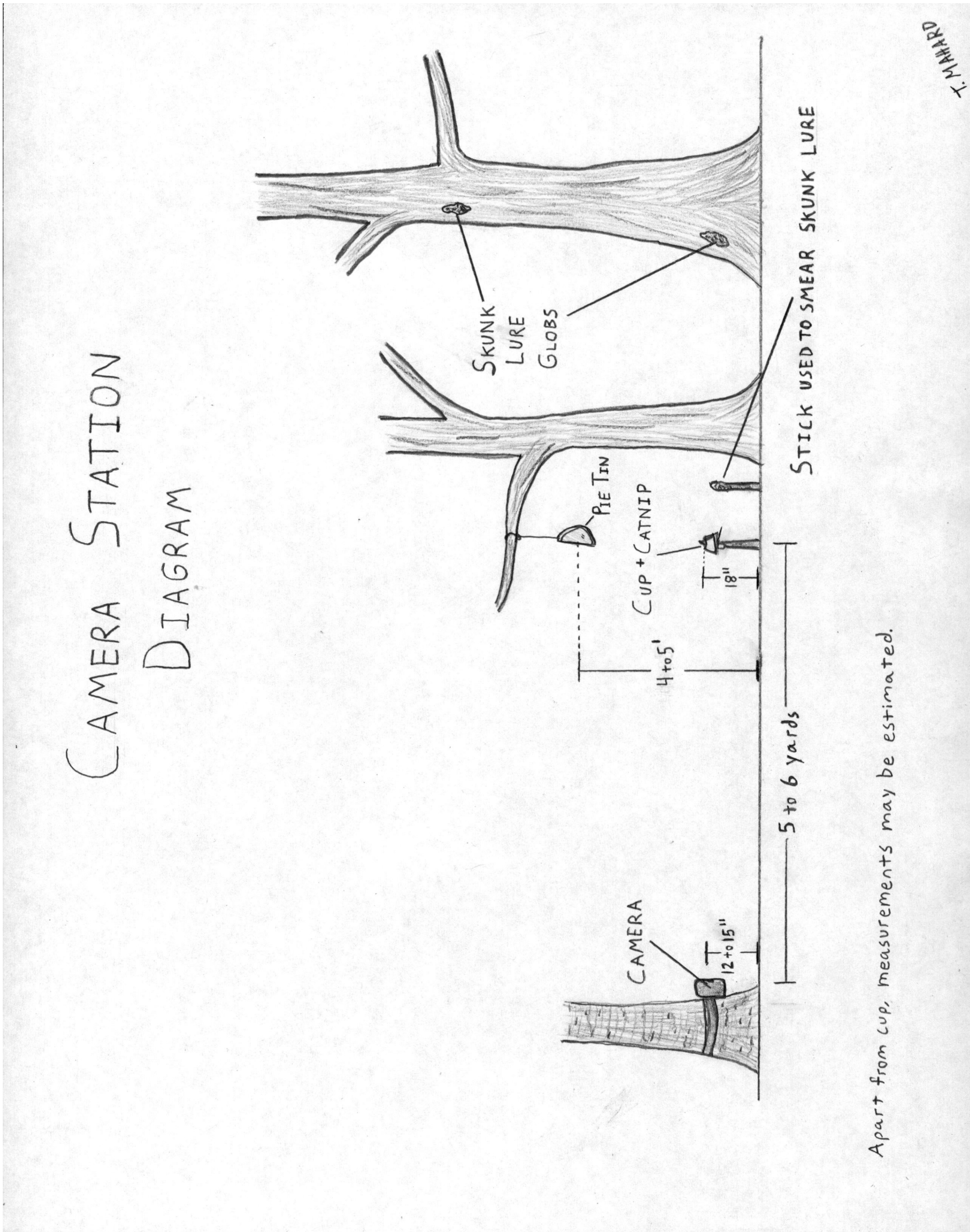
Selecting a location

The location of your camera station should be a wooded area. We would like to remind volunteers to be aware of hunting season. Please wear orange, and do not enter the woods if you feel unsafe doing so. Remember that it is not necessary for cameras to be deep into the woods, although that works fine, 20 paces or so from an edge works as well. We encourage use of camera locks, especially when placing cameras on property that is not your own. We can recommend affordable locks to you. If you are placing your camera on property that is not owned by you, we ask that you obtain landowner permission.

Please see the diagram on the following page for details of camera station setup. You should select a location with tree structure that allows for this setup. Dimensions are approximate, so finding a location should take less than a few minutes to accomplish.

Before and after you set up your camera station according to the diagram on the next page, please run through this checklist:

- Stick with zip-tied catnip wick and cup roughly 5 large paces (or 5-6 yards) from camera
- Pie tin suspended above catnip stick at approximately 4-5 feet from ground
- Use only ½ of the skunk lure in the container per 14-day survey period
- Skunk lure is smeared on a tree that is behind other lures and in view of camera lens
- One smear of skunk lure is below knee height; the other is above head height
- Camera is centered on attractants and properly angled both left to right and up and down
- Kneel down behind the cup and align it with the camera lens by eye
- Camera is approximately 12-15 inches above the ground
- Camera is set to timestamp photos with the correct date and time
- Camera is set to capture still images when triggered by motion
- Image resolution should be 5 to 8 MP, if possible
- Please use your discretion and knowledge of your camera when setting sensitivity, we recommend medium sensitivity to those unfamiliar with their cameras
- If possible, set your camera to take 3 photos per trigger and opt for a smaller interval between photo captures (20 seconds or less) if this is possible on your camera
- Clear away any small vegetation or branches directly in front of the camera that may trigger photographs in windy conditions
- Camera is turned on and collects photographs when you walk between it and the attractants


CAMERA STATION
DIAGRAM
CAMERA
12 to 15"
5 to 6 yards
4 to 5'
18"
CUP + CATNIP
PIE TIN
SKUNK
LURE
GLOBS
STICK USED TO SMEAR SKUNK LURE
T. MAHARD
Apart from cup, measurements may be estimated.

Project details

- Each volunteer will set up a camera station in one or more survey units within a study area
- We are attempting to have one camera station in each survey unit
- Surveys will last 14 to 17 days
- We ask that each volunteer complete two surveys (additional surveys may occur)
- For subsequent surveys, we recommend that the camera be moved to an unoccupied survey unit, or to a different location within the assigned survey unit, if feasible
- We request GPS coordinates of the camera's location (these may be obtained from a handheld GPS unit, most automobile GPS units, or from maps.google.com, email UNHbobcat@gmail.com for assistance)
- We would like all photographs collected during camera surveys
    - Preferably, this will occur through an internet dropbox, or memory cards may be mailed to UNH and will be returned to you
    - Data coincidentally collected on other species will be useful in other research

Timeline

October 23 - 31: Training sessions & attractant distribution

November 1 - 4: Deploy cameras to commence Survey 1

November 15 - 16: End Survey 1, commence Survey 2

November 29 - December 2: End Survey 2, commence Survey 3

December 13 – 16: End Survey 3

Catnip-soaked wick, zip tie, and cup on a stick

APPENDIX D. POSITIONAL ERROR FOR LOCATION DESCRIPTIONS

The following are methods developed to estimate geographic coordinates and associated positional error for exact locations of observed bobcats and camera stations based on location descriptions provided by citizen scientists.

In general, studies that rely on sightings of wildlife from the public lack detailed methods used to identify geographic coordinates based on descriptions provided by observers, and acknowledgement of positional error that may be associated with coordinates inferred from verbal descriptions, if present, is limited (e.g., Quinn 1995, Harrison 1998, Woolf et al. 2002, Webster and DeStefano 2004, Poessel et al. 2013). In this study, estimates of positional error helped to assess the spatial accuracy of sightings and camera survey data, and were necessary to determine which wildlife management units observations occurred within. These methods should also be used when assessing environmental features within the proximity of an observation (e.g., Broman et al. 2014, Sequeira et al. 2014). For example, habitat suitability (derived from a spatial model) values within a 1-km radius of a sighting location could be completely unrepresentative for locations with a spatial error of 2 km or more (Fig. D1). I used Google Earth to determine (when observer provided location description) or verify (when observer provided coordinates) coordinates representative of each sighting location. Using the point-radius method and many of the techniques of Wieczorek et al. (2004), I recorded an estimate of positional uncertainty to account for spatial discrepancy between the recorded coordinates and the true location of the animal at the time of the observation (Fig. D1). To accomplish this, locations provided by observers were regarded as areas rather than points (Fig. D2). Areas were defined according to location details provided by the observer. If not included with a locality description, coordinates were taken for the approximate centroid of the area in which the bobcat was observed and uncertainty was recorded as the distance from the centroid to the furthest point on the area's boundary.

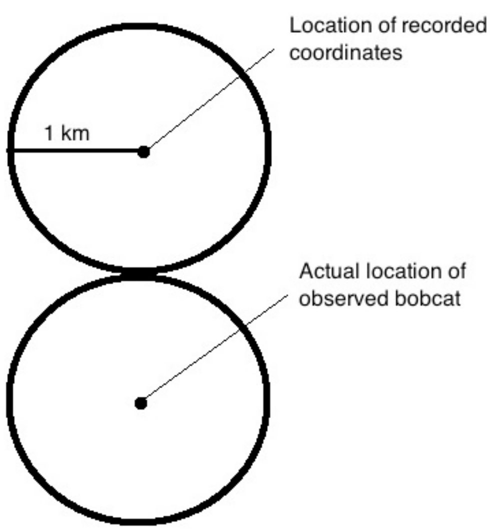


Figure D1. Example of an erroneous proximity analysis. In this case, variables are assessed within a 1-km radius of the recorded coordinates. However, the actual location of the observed animal was 2 km away from the recorded location.

Determination of uncertainty varied according to the type of location description and the amount of detail provided by the observer (Table D1).

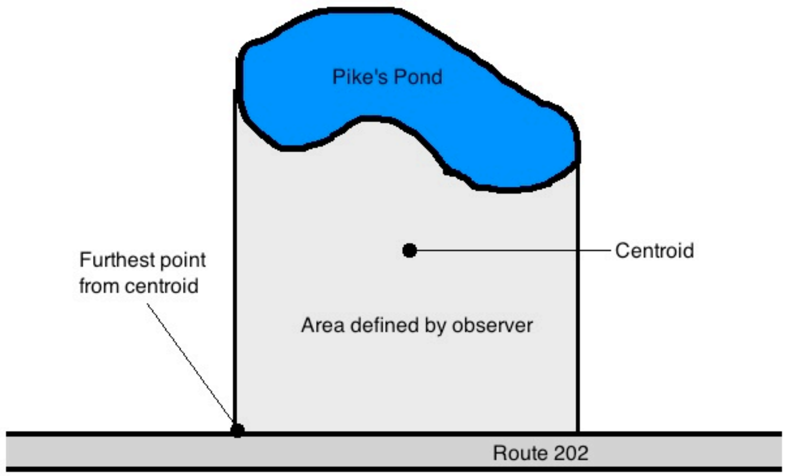


Figure D2. Example of method used to obtain coordinates and error estimate based on observer's location description. Example statement from observer: "bobcat was seen between Pike's Pond and Route 202". This statement defines the area shaded in light gray. The centroid and the furthest point on the area's boundary from the centroid are labeled. Error was recorded as the distance between these two points.

Coordinates of observation locations measured in the field from a GPS unit received an error estimate of 30 m. Coordinates obtained from mobile phones received an error estimate of 1000 m. These quantities are based on studies that tested the positional accuracy of GPS-equipped mobile phones and low-cost GPS units. Zandbergen and Barbeau (2011) found a 95th percentile of 23.9 m for horizontal positional error among samples of stationary fixes for two brands of mobile phone and two low-cost GPS units. Another study compared 6 commercial-grade GPS units and found that average error never exceeded 20 m (Wing et al. 2005). An error 30 m was suggested by (Wieczorek et al. 2012) and selected for this study as a conservative estimate. In testing positional error of the iPhone, Zandbergen (2009) found horizontal error under 15 m at the 95th percentile when the phone used satellites directly to determine its location. However, when the phone determined its location using WiFi or using cell towers rather than a direct satellite link, the 68th percentiles for horizontal error were 88 m (WiFi) and 827 m (cell towers). 1000 m was selected as a conservative estimate of uncertainty associated with coordinates obtained from mobile phones. Mobile phones are suspected to use these methods when satellite reception or dilution of precision is poor. Additional potential sources of error that could not be estimated included the observer's ability to recall an observation location when measuring coordinates post-sighting and typos during communication with researchers.

Table D1. Method for determining coordinates of bobcat locations and associated positional errors for different types of location descriptions provided by citizen scientists. Location descriptions included coordinates from GPS units and mobile phones, coordinates (or hyperlinks) from online mapping sources (e.g., Google Maps) and unknown sources, road names, street addresses, and offsets from landmarks or named places (e.g., street intersections, buildings, addresses, water bodies, parks).

Location description	Coordinates	Uncertainty
Coordinates from GPS unit	Provided by volunteer	30 m
Coordinates from mobile phone	Provided by volunteer	1000 m
Coordinates from online mapping or unknown source	Provided by volunteer, recorded if verifiable	Distance from coordinates to furthest point on edge of verified feature
Street address or road	Closest point on road to its centroid	Destance from coordinates to furthest point on road
Offset from landmark or named place	Specified location	Methods of Wieczorek et al. (2004, 2012)

Coordinates from unknown sources, or from online mapping sources (e.g., Google Maps) that were not accompanied by a written description of the location were not recorded. Accuracy beyond the township resolution was impossible to assess in these cases. If coordinates were supplemented with a matching written description that identified some feature in which the sighting occurred (e.g., back yard, frozen pond, state park, road, hayfield, wetland) coordinates for the centroid of that feature were recorded and error was taken as the distance from those coordinates to the furthest point on the feature's edge (Wieczorek et al. 2004; Fig. D2).

When observers reported a road as a location (e.g., "seen crossing Wildcat Lane in Barrington, NH"), coordinates were taken for the point on the road closest to its centroid and uncertainty was taken as the distance from the point to the furthest point on the road. I assumed that Google Earth correctly identified roads and that observers did not mistake the road they observed a bobcat on for another road.

Studies that obtain coordinates of sightings from street addresses (Webster and DeStefano 2004, Nagy et al. 2012, Broman et al. 2014) employ some sort of geocoding (i.e., matching geographic features such as addresses to geographic coordinates). There are a variety of geocoding methods and known accuracy issues associated with them (Goldberg et al. 2007). The Topographically Integrated Geographic Encoding and Referencing (TIGER) database (U.S. Census Bureau), a frequently used geocoding source, uses an interpolation algorithm to estimate the geographic coordinates of an address along a street (Karimi et al. 2004). For TIGER, and the Google Maps API (Application Programming Interface) used by Google Maps and Google Earth, geocoding of addresses may have significant spatial error, particularly along longer streets and in rural areas (Cayo and Talbot 2003, Goldberg et al. 2007). This error is a result of assumptions inherent in the geocoding algorithms (e.g., homogeneous property parcel size and distribution along streets). Further, sightings that come from particularly large property parcels would have limited accuracy, unless the observer provided more descriptive location information than an address. On the other hand, accurate coordinates can likely be obtained for sightings that come from small, evenly spaced property parcels on short roads. Because of the uncertainties associated with the spatial error of geocoded addresses, and because many of the provided addresses occurred in rural areas and on long streets, I ignored postal address numbers and used street names only to determine locations (Table D1).

The methods of Wieczorek et al. (2004) were used to determine coordinates and spatial error when observers provided a location description as an offset from a landmark or named place that was identifiable on Google Maps or Google Earth (e.g., street intersection, water body, wetland, state park, mountain). Coordinates were taken at the specified distance and direction from the centroid of the landmark (e.g., “two kilometers northeast of Nippo Pond”) using methods for estimating uncertainty based on precision as described by Wieczorek et al. (2004). If observers provided a distance from a landmark without a direction, the coordinates of the centroid of the landmark were recorded. If an observer provided a location relative to an identifiable landmark and included a direction with no distance, coordinates were recorded at the halfway point between the landmark and the township boundary in the specified direction. Error was taken as the distance between the centroid of the landmark and the recorded coordinates. If the observer reported that a sighting occurred “near” a landmark and provided the township of occurrence, but provided no distance or direction, the coordinates of the landmark’s centroid were recorded and error was taken as half of the distance from the landmark to the furthest point on the township boundary.

Coordinates were not recorded if the location provided by the observer did not match the reported township, unless the location was just outside of the reported township and it was obvious that the observer had unknowingly crossed a township boundary. In this scenario I recorded the township that corresponded to the location described by the observer.

APPENDIX E. HUNTER SURVEY LETTER AND CARD

Hunter survey letter and cards mailed to registered deer hunters in New Hampshire, 2012.

New Hampshire
Fish and Game Department

11 Hazen Drive, Concord, NH 03301-6500
Headquarters: (603) 271-3421
Web site: WildNH.com

TDD Access: Relay NH 1-800-735-2964
FAX (603) 271-1438
E-mail: wildlife@wildlife.nh.gov

Glenn Normandeau,
Executive Director

Dear White-tailed Deer Hunter:

This is the 21st year the New Hampshire Fish and Game Department is asking a portion of our deer hunters to keep a diary of hours hunted and game seen during muzzleloader season and the first 12 days of the regular firearm season. This survey is extremely valuable in tracking moose, deer, bobcat and bear abundance and distribution. As this information is vital to our management programs, I hope that you will support this effort by assisting with this very valuable survey.

When filling out the survey, it is important that you fill it out completely and legibly. In particular, we must have the date, WMU and town hunted, hours hunted, and deer, moose, bobcat and bear seen for each day hunted. Please use the WMU map on the back of the card when designating the WMU in which you have hunted. Note that to better manage deer populations, WMUs D2 and G have been split into D2E, D2W and G1, G2. If you need additional space, please make copies of the survey card. Please send your card or cards in as soon as you're finished hunting or no later than December 1, 2012. This allows us to enter and analyze the information in a timely manner. Please fill out your card for every day hunted even if you did not see any animals.

Once again this year, Thompson/Center Arms Co., Inc., and Sturm, Ruger & Co. have generously donated raffle prizes for those returning a usable diary card. These prizes are listed on the back of your survey card. Their continuing support of this effort to collect hunter-based game management information is greatly appreciated. To participate in the raffle, you must fill out the name and address portion of the survey card, as well as the diary portion of the card with this year's deer hunting information.

If you have any questions on the program, please call me at (603) 744-5470. Thank you again for your participation in this program and good luck this season! Happy hunting!

Respectfully,

Kristine M. Rines
Moose Project Leader

EXAMPLE:

DEER HUNTER SURVEY FORM – RETURN ON OR BEFORE DEC. 1, 2012

TOWN OF RESIDENCE: NEWTOWN STATE: NH

NAME (optional): JOHN Q HUNTER PHONE # (optional): 555-1000

ADDRESS (optional): 46 MAIN ST., NEWTOWN, NH 03000 DATE OF BIRTH (optional): 5/10/65

MONTH	DAY	WMU	TOWN HUNTED	# HOURS HUNTED	# DEER SEEN	# BEAR SEEN	# MOOSE SEEN BULL	# MOOSE SEEN COW	# MOOSE SEEN CALF	# MOOSE SEEN UNK	# BOBCAT SEEN
11	03	A1	PITTSBURG	7.5	2	1		1	2		
11	04	A2	PITTSBURG	5.0	2	3					
11	14	H1	MARLOW	7.0							
11	15	D2W	LYMAN	10	3			1			

DEER HUNTER SURVEY CARD – RETURN ON OR BEFORE DEC. 1, 2012

Please report THIS YEAR'S muzzleloader and first 12 days of firearms hunting information.

TOWN OF RESIDENCE: ____________________ STATE: ____

*NAME (optional): ____________________ *PHONE # (optional): ____________________

*ADDRESS (optional): ____________________ DATE OF BIRTH: ____________________

2012 MONTH	DAY	WMU	TOWN HUNTED	# HOURS HUNTED	# DEER SEEN	# BEAR SEEN	# MOOSE SEEN BULL	COW	CALF	UNK	# BOBCAT SEEN

*Include this information if you wish to participate in the lottery for survey prizes.

F&W12013B.indd

(over)

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

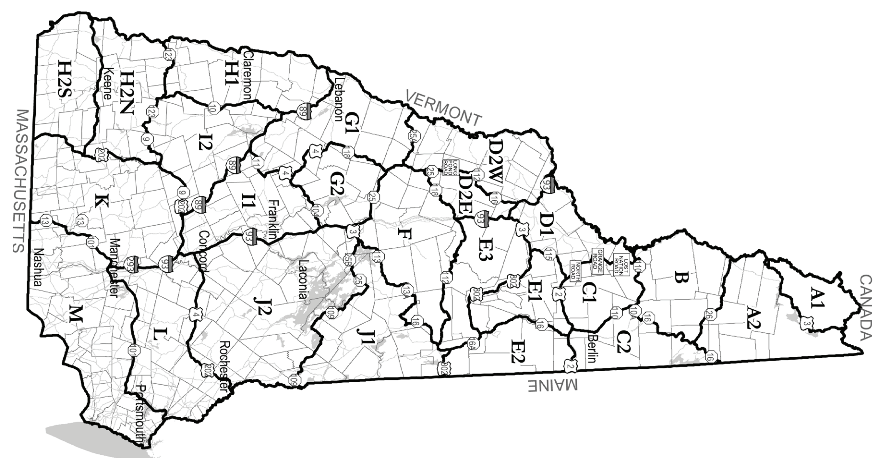
BUSINESS REPLY MAIL

FIRST-CLASS MAIL PERMIT NO. 2126 CONCORD NH

POSTAGE WILL BE PAID BY ADDRESSEE

WILDLIFE DIVISION
NH FISH AND GAME DEPARTMENT
11 HAZEN DR
CONCORD NH 03301-9853

Please use these WMU designations when filling in your card.



TO MAIL: FOLD AND SEAL THIS EDGE - NO POSTAGE NECESSARY

RETURN YOUR SURVEY AND WIN A PRIZE!

If you participate in this survey and send your legible and completed card in by December 1, 2012, you will be entered into a June drawing to win either a model M77 Hawkeye deer rifle with the caliber of your choosing donated by Sturm, Ruger & Co. or a Thompson/Center Arms muzzleloader.

The New Hampshire Fish and Game Department thanks
Thompson/Center Arms Co.,Inc.,
and Sturm, Ruger & Co.
for their generous donations
and support of our wildlife heritage.

APPENDIX F. HUNTER SURVEY DATA AND RATES

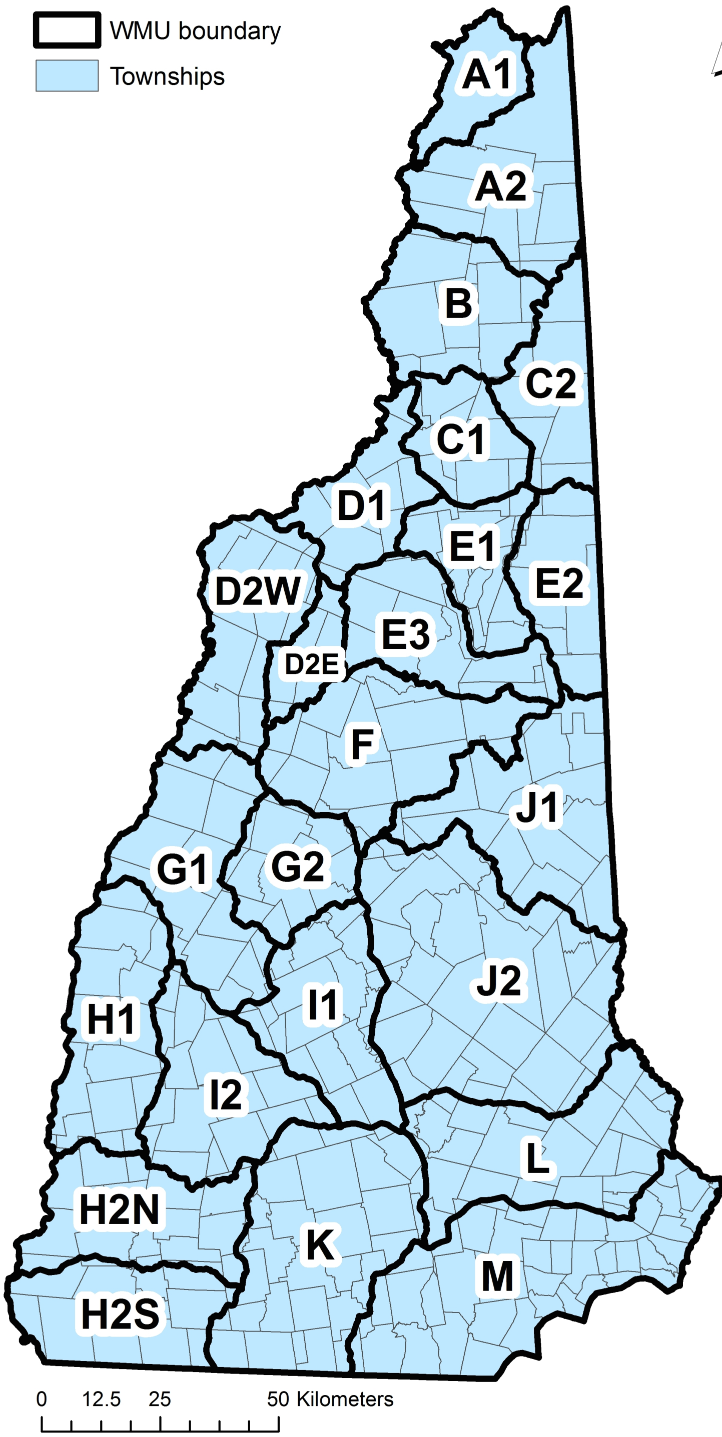
Summary of hunter survey data and observation rates of bobcats based on numbers of outings, hours, and outings*hours for each wildlife management unit (WMU) in New Hampshire. Use of outings*hours as a parameter for effort may provide a better index of bobcat relative abundance by accounting for two factors that both influence effort independently. In this case, squaring the number of outings with bobcat observed maintains a linear relationship between the abundance and effort parameters. For each WMU in the table below, O = number of hunter outing records; H = summation of hours hunted; O_B = number of outings during which 1 or more bobcat were seen.

WMU	O	H	O_B	H/O	$[O_B/O]$ x10^3	$[O_B/H]$ x10^3	$[O_B^2/OH]$ x10^5
A1	1,415	9,824	2	6.94	1.41	0.20	0.03
A2	2,406	15,850	8	6.59	3.33	0.50	0.17
B	1,769	9,950	8	5.62	4.52	0.80	0.36
C1	710	3,705	8	5.22	11.27	2.16	2.43
C2	940	5,139	7	5.47	7.45	1.36	1.01
D1	1,542	6,909	17	4.48	11.02	2.46	2.71
D2E	76	475	0	6.25	0.00	0.00	0.00
D2W	4,639	22,425	49	4.83	10.56	2.19	2.31
E1	145	725	0	5.00	0.00	0.00	0.00
E2	269	1,573	0	5.85	0.00	0.00	0.00
E3	96	611	1	6.36	10.42	1.64	1.70
F	1,122	5,986	6	5.33	5.35	1.00	0.54
G1	3,023	16,732	29	5.53	9.59	1.73	1.66
G2	1,088	5,573	3	5.12	2.76	0.54	0.15
H1	5,766	32,079	45	5.56	7.80	1.40	1.09
H2N	4,697	25,712	48	5.47	10.22	1.87	1.91
H2S	4,322	24,258	38	5.61	8.79	1.57	1.38
I1	3,076	15,331	31	4.98	10.08	2.02	2.04
I2	2,824	14,629	32	5.18	11.33	2.19	2.48
J1	3,055	16,782	28	5.49	9.17	1.67	1.53
J2	12,572	66,430	113	5.28	8.99	1.70	1.53
K	10,139	51,454	122	5.07	12.03	2.37	2.85
L	10,051	51,831	46	5.16	4.58	0.89	0.41
M	4,357	21,079	14	4.84	3.21	0.66	0.21

Hunter survey data was collected by the New Hampshire Fish and Game Department from 2009 through 2013. Records for which the reported WMU and town were not spatially coincident, or for which the entry in the “town” field could not be matched to a town in the New Hampshire Political Boundaries layer (Complex Systems Research Center, Durham, NH), were excluded from analyses. Records for which the WMU was not fully specified (e.g., “A” instead of “A1” or “A2”; Appendix G) were excluded unless the fully specified WMU could be inferred based on the reported township and the geography of its boundaries. Hunter survey records with null entries or <0.5 in the ‘# HOURS HUNTED’ column (n=43), were excluded (see Appendix E), as have entries with contradicting WMU and town designations.

APPENDIX G. MAP OF TOWNSHIP AND WMU BOUNDARIES

Boundaries for New Hampshire townships (n=259) with Wildlife Management Units for deer (n=24) overlain.



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