Estimating density of bobcats with capture-mark-recapture data from camera traps W-187-R

Final Report FY 2018

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FINAL REPORT – FY2016-2017
Estimating density of bobcats with capture-mark-recapture data from camera traps
Federal Aid in Wildlife Restoration
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EXECUTIVE SUMMARY

Objectives

1) Estimate density of a local population of bobcats in northern Illinois (i.e., north of US Route 26) by 30 June 2017.
2) Compare rates of capture/recapture for different spatial arrays of camera traps by 30 June 2017.
3) Estimate home ranges of bobcats inhabiting northern Illinois and relationships with detection by camera traps by 30 June 2017.
4) Recommend efficient protocols for estimating density of bobcats across northern Illinois by 30 June 2017.

Methods

We conducted camera surveys using 160 passive infrared-triggered remote cameras (e.g., (Browning Recon Force, Model BTC-7FHD, Prometheus Group, LLC Birmingham, Alabama, USA) for 3-month seasonal sampling intervals; seasons were defined by dividing the year into biologically meaningful periods that approximate changes in phenology and bobcat reproductive ecology (Nielsen and Woolf 2002*a*). We defined the breeding and parturition–kitten rearing seasons as 1 November–30 April and 1 May–31 October, respectively (Nielsen and Woolf 2002*a*). Prior to camera deployment, we divided our study site into 9 km^2 camera survey units (i.e., approximate diameter of smallest recorded home range size for a female bobcat in southern Illinois; Nielsen and Woolf 2001). We generated centroid locations for each camera survey unit and randomly selected 60–80 units (i.e., 15–20 units per county) that contained ≥50% forest cover for camera surveying. We navigated to camera station (centroid) locations and placed two cameras opposite each other on both sides of known travel corridors. In cases when centroid locations were not located in optimal (forested) habitat, we adjusted them by placing cameras in or along the edge of the nearest forested habitat.

We placed camera stations at a mean height of 0.3 m above ground and fastened them to sturdy vegetation or wooden surveyor stakes (61 cm × 7.62 cm) at a 4.6 m spacing staggered by 4.6 m (Fig. 2). This increased the chances of obtaining at least one high quality image of both sides of the individual (Kelly et al. 2008, Rovero et al. 2013, Foster and Harmsen 2012, Thornton and Pekins 2015). We hung visual attractants (i.e., compact discs) from vegetation out of the field of view (Nielsen and McCollough 2009) of camera stations. A capture event consisted of a photograph of a uniquely identifiable bobcat at ≥1 camera at a station. Individual bobcats were identified by comparing bobcat photos using standard pelt pattern protocol outlined by Heilbrun et al. (2003). When applicable, we also used capture photos of radio-collared bobcats. We calculated total number of bobcat events and total number of photographs for bobcats as measures of trap success (calculated number of bobcat events per 100 trap nights;

Kelly et al. 2008). We defined detection efficiency of each event as the number of camera stations that photograph ≥1 bobcat divided by the total number of active stations (Larrucea et al. 2007).

We tested the potential effect of camera density on number of bobcat photo-capture and recaptures using a modification of the protocol described previously by Larrucea et al. (2007). We evaluated six densities (1, 2, 4, 6, 8, and 10 camera stations per 9 km^2) by placing grids of the appropriate size over camera survey units; we defined 1–2 cameras stations/9km^2 as low density, 4–6 cameras/9km^2 as moderate density, and 8–10 camera stations/9 km^2 as high density. We determined locations of camera stations by placing 25 0.36-km^2 (600 × 600-m) square grids over the 9 km^2 camera survey units (Fig. 2) and placing cameras as close to the center of each grid along the nearest travel corridor (Larrucea et al. 2007). Given the limited availability of forested cover (25%) throughout our study site, we selected 0.36-km^2 grids to maximize the likelihood of deploying camera stations in high-quality (>50% forested cover) habitat. Additionally, we increased the likelihood of capturing and recapturing bobcats by deploying camera stations within known bobcat (i.e., radio-collared) home ranges. We conducted camera density evaluations during two 30-day sampling intervals during 15 May –15 June 2016 and 20 April –20 May 2017. All cameras were operational 24 hours per day set on rapid-fire mode (3 shot burst) with a delay of 1 minute (Foster and Harmsen 2012, Rich et al. 2014).

We used Bayesian analysis to develop a spatial capture-recapture (SCR) model for estimating bobcat density across our study site per the recommendations of Royle et al. (2011). Unlike classical closed-population capture-recapture models, SCR models formally relate encounters of individuals to where individuals spend time over trapping intervals (Royle et al. 2011). Thus, individuals that center activity patterns across a defined area over a given period of time should be expected to encounter a trap as a function of the distance between that animal's activity center and the trap (Royle et al. 2010). Functionally, SCR models are essentially standard, closed population models augmented by a spatial random effect that describes the juxtaposition of individuals with the trap array (Royle et al. 2011). We conducted Bayesian analyses using Markov-Chain Monte Carlo (MCMC) simulations over the region where camera station locations were distributed (i.e., state-space of the point process; Royle et al. 2011). We followed the procedures of Royle et al. (2011) to define the continuous state space by overlaying the trap array on a square region extending 20 km beyond camera traps in each cardinal direction. We scaled the state-space by defining it near the origin and fit models for a range of choices of the square state-space based on buffers from 5 to 20 km (Royle et al. 2014). We modified the wolvSCR0 function provided in the R package scrbook and fit models in JAGS using data augmentation with M = 100–150 individuals, a state-space buffer of 1 standardized unit, three MCMC chains each of 12,000 total iterations, and discarding the first 2000 as burn-ins (Royle et al. 2014). To meet basic assumptions of closed populations, we limited our SCR analysis to data collected during the 2017 breeding season (1 February 2017 to 18 April 2017). We used one factor analysis of variance and simple correlation analyses to evaluate potential effects associations between camera density and photo-capture and recapture rates of bobcats. We used Tukey's HSD post-hoc analyses to test for differences in capture and recapture rates between camera densities. We conducted all analyses using Program R (R Core Team 2015); statistical tests were conducted at $\alpha = 0.05$.

We trapped bobcats during 2 consecutive winters between 1 January 2016 and 9 March 2017 with Camtrip cage traps (guillotine door, frameless wire mesh box traps [~25.4 × 48.26 × 91.44 cm]; Camtrip cages, Barstow, CA) and MB-550 offset modified foot hold traps (Minnesota trapping products, Pennock, MN). Additionally, we handled individuals incidentally live-trapped by licensed private trappers if they were uninjured and within the boundaries of our study area. We immobilized trapped bobcats with an intramuscular injection with a combination of ketamine hydrochloride (HCL; 10 mg/kg) and xylazine HCl (1.5 mg/kg; Kreeger and Franzmann 1996). We sexed, weighed, recorded morphometric data, and estimated age of bobcats based on body mass (e.g., animals > 5 kg will be classified as adults [≥ 2 yrs.], individuals < 5 kg will be considered juveniles; Nielsen et al. 2001, 2002*a*, 2002*b*). We fitted each bobcat (≥ 5 kg) with uniquely numbered ear tags (Standard Rototag: https://www.enasco.com/product) and a very high frequency radiocollar (150–151 MHz; Telonics, Mesa, AZ; Model 315-S6A) equipped with mortality sensors. In all cases, we ensured that radiocollars weighed ≤ 5% of the individual's body weight. Prior to release, we administered an intramuscular injection of tolazoline HCl (4 mg/kg) as an antagonist to xylazine HCl (Kreeger and Franzmann 1996) to aid in recover time. Capture and handling protocols were approved by the Institutional Animal Care and Use Committee at Western Illinois University (approval number 15-09) and followed guidelines for the care and use of animals approved by the American Society of Mammalogists (Sikes et al. 2016).

We used standard ground telemetry techniques to monitor movement of bobcats on average once per week from January 2016 through May 2017, after which field work was terminated. We rotated telemetry tracking efforts so that we collected locations throughout the entire 24 hr period, so we captured habitats for both resting and foraging behavior. We used standard ground radio telemetry techniques to track bobcats (White and Garrott 1990). We used radio telemetry, capture, and visual locations to determine point locations of radiocollared bobcats. To the extent possible, we minimize time between first and last bearings (i.e., ≤20 min; Nielsen and Woolf 2001) when locating animals to reduce the likelihood of animal movement, and thus bias in location data. Additionally, we collected locations of individuals ≥20 hr apart (Nielsen and Woolf 2001) to minimize temporal bias in home range estimates. We estimated animal locations using Program LOCATE III using the maximum likelihood estimator (Nams 1990) with a minimum of 2 azimuths for each location, and to calculate bearing error and home range error polygons (Nielsen and Woolf 2001).

We entered locations into a geographic information system, and analyze them to determine home range use of adult resident bobcats. We calculated home ranges and core areas using an adaptive kernel estimator with least squares cross validation (Worton 1989, Kie et al. 1996, Seaman et al. 1999) in the Animal Movements extension (Hooge and Eichenlaub 1997) for ArcView. We used a 95% utilization distribution (UD) to calculate home ranges and a 50% UD to calculate core areas (Powell 2000, Tucker et al. 2008). We generated home-range and core area estimates using an ad hoc smoothing parameter by choosing the smallest increment of the reference bandwidth (h_{ref}) that results in a contiguous 95% kernel home range (i.e., $h_{ad\ hoc} = 0.9 \times h_{ref}$, $0.8 \times h_{ref}$, etc; Kie 2013). Kernel estimators are nonparametric and thus are not based on an assumption that the data conform to specified distribution parameters (Seaman et al. 1999). Due to limited sample sizes, we limited our analyses to annual home range calculations using a minimum of 20 locations (Seaman et al. 1999) for each radio-collared bobcat. To avoid potential biases in the number of locations collected between individuals and seasons, we attempted to distribute telemetry location efforts evenly among individuals, both spatially (across treatment plots) and temporally (seasonally). We considered a bobcat a resident if it did not make a permanent one-way movement outside the boundary of its previously established home or natal range (Kamler and Gipson 2000, Tucker et al. 2008). To approximate a normal distribution, we log transformed all 95% and 50% UDs (Ramsey and Schafer 2002, Tucker et al. 2008).

To evaluate potential effects of intrinsic (i.e., sex) and habitat characteristics on bobcat home range use, we created a 3,770-m circular analysis regions around geometric centers of each individual (Kie et al. 2002, Bowyer and Kie 2006); the associated circular analysis region (43.22 km^2) comprised the land area that was the approximate mean 95% home range size of adult female bobcats across our four county study site. Further, this area encompassed all 50% core areas of male bobcats, thus was likely reflective of the highest quality habitat across our study site. To determine habitat characteristics associated with each individual, we overlaid circular analysis regions on the 2011 National Land Cover Data set (NLCD) and calculated habitat composition (% composition of each buffer) using Geospatial Modeling Environment (http://www.spatialecology.com/gme) in ArcGIS 10.3 (Esri, Inc., Redlands, California, USA). We re-classified land cover data into 5 categories; grassland/pasture-hay/shrubs, forested cover, cultivated crops, wetlands, and open water. For a detailed description of land cover categories, see the NLCD website (http://www.mrlc. gov/nlcd06_ leg.php). We used FRAGSTATS Version 4.2 to calculate landscape and class-level metrics associated with each buffered area by county (McGarigal et al. 2002).

We selected the intrinsic and habitat factors (Table 5) that we considered biologically meaningful to bobcat ecology. Further, these variables also have been identified as important factors influencing bobcat home range use in agriculturally dominated landscapes across the Midwest (Tucker et al. 2008). We broadly defined habitat variables as a) percent cover (percent of landscape comprised of habitat cover type), b) patch density (number of patches/100 ha of the cover type), c) shape index (i.e., average departure of patches from maximum compaction), and d) landscape shape index (i.e., standardized measure of the edge for all cover type patches), e) percent of patch mixing between habitat classes, and f) percent of patch aggregation for specified habitat classes (McGarigal et al. 2002). Because of the small number of bobcats available for home range analyses, we limited our model set to single parameter models evaluating main effects only (Table 6).

We used 1-way analysis of variance (ANOVA) limited to main effects to evaluate potential effects of sex and habitat parameters on 95% and 50% home range use by bobcats. Additionally, we used 1-way ANOVA to test for intersexual differences in body mass. We generated Type III sums of squares in ANOVA models to account for our use of cross-classification designs with unbalanced data (SAS Institute Inc. 2008). We conducted statistical analyses using Program R (R Core Team 2015).

Major Accomplishments and Findings

We deployed 50 camera stations over a 77-day period from 1 February–18 April 2017. Mean operational time of cameras was 52 days, though varied from 32 to 67 days. We captured 23 uniquely identifiable bobcats 115 times and recaptured these same individuals 92 times. We photographed bobcats at 36 of 50 (72%) camera stations. Due to unidentifiable features of bobcats at 2 camera stations and theft of cameras at one station, we used 34 of 49 camera stations in analyses. Individual encounter frequencies ranged from 4 individual captured 1 time in a single trap to 1 individual captured 17 times in 5 different traps. For the 5-km continuous state-space model, our analysis revealed a slight effect on the posterior distribution of density because the state-space is not sufficiently large (Table 2). However, posterior summary statistics for the 10-km, 15-km, and 20-km continuous state-space models were similar. Using the posterior mean from the state-space based on the 10-km buffer, the point estimate of bobcat density was 1.44 individuals per 100 km^2. Densities ranged from 1.44–1.57 bobcats per 100 km^2 with a 95% posterior interval of 1.07 to 1.90. Our estimates of R-hat was 1.00 for all chains, indicating good model convergence within and between chains.

We deployed 31 camera stations during two sampling intervals (15 May to 15 Jun 2016, 20 Apr to 20 May 2017) over 1,800 trap nights. Our analyses revealed that effects of camera density on bobcat detection probability was marginally significant ($F_{2,3}$ = 7.33, P = 0.07, R^2 = 0.22) and most evident between low and moderate camera station densities; probability of detection was similar (P = 0.27) between moderate and high camera densities. Similarly, probability of detecting bobcats was similar (P = 0.29) between low and high camera densities; maximum detection was associated with moderate camera densities. Similarly, the number of individual bobcats detected varied ($F_{2,3}$ = 9.93, P = 0.04) with camera density; moderate and high camera densities yielded greater ($P \leq 0.05$) numbers of individuals than lower camera densities, though were similar (P = 0.94) between moderate and higher camera densities; we detected no more than 4 individual bobcats at any 1 camera station. We documented no differences ($F_{2,3}$ = 4.21, P = 0.14) in recapture rates between low and high camera densities, though correlation analyses suggested positive associations (R^2 = 0.71) between recapture rates and increasing camera densities.

We live trapped 22 bobcats (13 male, 9 female) between 1 July 2015 and 30 Jun 2017. We collected 347 locations from those individuals from 3 Jan 2016 to 1 Jun 2017. Mean body mass of adults at capture varied ($F_{1,20}$ = 23.28, P = 0.002) for male ($\bar{x}$=11.40 kg, SE = 0.63, n = 14) and female ($\bar{x}$=7.74 kg SE = 0.18 n = 8) bobcats. We censored 9 individuals from our home range analyses due to mortality (n = 3), lost contact (n = 3), dispersal (n = 1), and insufficient numbers of relocations (n = 2), we conducted home range analyses using 13 individuals. Mean annual home range and core area sizes were 98.2 km^2 (SE = 30.66) and 15.4 km^2 (SE = 4.38), respectively. We documented significant differences ($F_{1,11}$ = 6.82, P = 0.02) in 95% home range sizes between males ($\bar{x}$ = 186.14 km^2 (SE = 57.61, n = 5) and females ($\bar{x}$ =43.22 km^2, SE = 17.65, n = 8). Similarly, core area size varied ($F_{1,11}$ = 7.79, P = 0.02) between males ($\bar{x}$ = 28.20 km^2, SE = 8.07) and females ($\bar{x}$ = 7.41 km^2, SE = 2.80). However, our analyses revealed no relationships ($F_{1,11} \leq 2.39$, $P \geq 0.15$) between habitat variables and home range use by bobcats; small sample sizes likely precluded our ability to detect habitat effects on patterns of space use by male and female bobcats.

We provide the first application of SCR models to estimate density of bobcats across the species' geographic range. We have shown that variation in the state-space extending beyond trap arrays affect bobcat density estimates and should be sufficiently large to minimize encountering individuals with activity centers (i.e., home ranges) beyond the state-space boundary. Increased size of home ranges of bobcats across Midwestern landscapes may necessitate the use of relatively coarser survey grids in SCR models to account for frequent movements to and from the state space or whose core areas are positioned beyond camera survey unit boundaries. Similarly, when photo-capture and recapture rates are a function of camera density, modifying camera trapping techniques by deploying moderate camera densities or repositioning cameras to more productive areas within survey grids may improve capture success in low density bobcat populations throughout Midwestern landscapes.

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NARRATIVE

<u>STUDY W-187-R</u>: ESTIMATING DENSITY OF BOBCATS WITH CAPTURE-MARK-RECAPTURE DATA FROM CAMERA TRAPS

Objectives: 1) *Estimate density of a local population of bobcats in west-central Illinois (i.e., north of US Route 26) by 30 June 2017.*

2) *Compare rates of capture/recapture for different spatial arrays of camera traps by 30 June 2017.*

INTRODUCTION

The bobcat (*Lynx rufus*) is an elusive mesocarnivore that occupies relatively large home ranges (Tucker et al. 2008), undertakes long dispersal movements (Nielsen and Woolf 2003, Johnson et al. 2010), and occurs at relative low densities (Larrucea et al. 2007). For these reasons, estimating density of bobcats has been difficult and early attempts have relied primarily on techniques that lack measures of accuracy and precision, including indices of relative abundance such as trap-nights per individual captured (Wood and Odum 1964, Jenkins et al. 1979), harvest (O'Brian and Boudreau 1998), snow tracking (Golden 1995), mail questionnaires (Anderson 1987), and scent-station surveys (Linhart and Knowlton 1975, Johnson and Pelton 1981, Conner et al. 1993). Previous studies have identified sex and age-specific biases in each of these methods (Diefenbach et al. 1994), none of which considered the spatial context of the data.

Closed population models have been used extensively to estimate density and abundance of animal populations from standardized trap arrays that provide information on encounter histories of study animals (Borchers et al. 2002). However, model-derived estimates of population density is difficult to interpret because of uncertainty in what constitutes the effective area sampled by trap arrays (i.e., area from which captured and recaptured individuals are drawn;

Royle et al. 2011). Previous studies have recognized the difficulty in defining the sampling area and have included a wide range of ad hoc approaches including drawing polygons around and buffering trapping arrays. Unfortunately, these approaches are arbitrary and inconsistent between studies, introduce uncertainty into density estimation, and fails to account for heterogeneity in encounter histories among individuals (Royle et al. 2010).

A variety of increasingly sophisticated methods are available for estimating population density from capture-recapture (CR) studies (Pollock et al. 1990, Seber 1992, Pledger 2000, Williams et al. 2002, Efford 2004). Among these, spatial capture-recapture (SCR) models (Borchers and Effort 2008, Royle and Young 2008, Royle et al. 2010) provide a rigorous analytical technique for inference that extends standard closed population models (Otis et al. 1978, Lukacs and Burnham 2005) by including a spatially explicit model that accounts for the distribution of individuals in space (Royle et al. 2010). An advantage of SCR models is that they rely on spatial information readily available with camera data and use distance between traps and animal activity centers to model spatially explicit (i.e., camera trap) encounter probabilities (Royle et al. 2010). Spatial capture-recapture models have been used in population density estimation for a range of carnivores, including bears (*Ursus americanus*; Gardner et al. 2010*a*), tigers (*Panthera tigris*; Royle et al. 2009), and small cats (Gardner et al. 2010*b*). Nevertheless, reliability of density estimates varies widely between species, in part due to heterogeneity in the number and placement of camera stations among studies. For instance, Karanth and Nichols (1988) spaced cameras 2–3 km apart along road transects, while Soisalo and Cavalcanti (2006) systematically placed 2–3 cameras within the home ranges of jaguars at sites where radiotelemetry locations were clustered. Kawanishi and Sunquist (2004) used 1 camera/4 km^2 on study sites where roads generally did not occur, whereas Jacobsen et al. (1997) used camera densities of 0.4–1.5 cameras/km^2 across their study site. Nielsen and McCollough (2009) reported camera stocking rates of 1 camera/2.5km^2 to detect Canada lynx (*Lynx canadensis*) in northern Maine. To our knowledge, the only previous evaluation of potential effects of variable camera densities on bobcat density estimation was by Larrucea et al. (2007), who determined that animal densities and detection probabilities increased with increasing camera density (0.5 to 8 cameras/km^2) and study duration, respectively. Thus, our objectives were to 1) develop a spatially explicit capture-recapture model for estimating bobcat density and 2) evaluate potential effects of camera density on capture and recapture rates of bobcats in agriculturally dominated landscapes of west-central Illinois.

STUDY AREA

Broadly speaking, our study was conducted over four counties (Hancock, Schuyler, Fulton, and McDonough) in west-central Illinois (Fig. 1). The 7,067 km^2 study area is rural and sparsely populated (13.8 persons/km^2; 2010 U.S. Census Bureau). The majority (56%) of land across the 4-county area was characterized by row-crop (i.e., corn [*Zea mays*] and soybeans [*Glycine max*]) agriculture, whereas remaining acreage constituted forest (25%), shrubs (1%), development (6%), open water (2%), and pasture/hay (10%; Luman et al. 1996). Land elevation across the region ranged from 130 to 244 m above sea level (Walker 2001, Preloger 2002, Tegeler 2003). Dominant overstory woody vegetation consisted of white oak (*Quercus alba*), post oak (*Q. stellata*), black oak (*Q. velutina*), and mockernut hickory (*Carya alba*; Luman et al. 1996).

METHODS

Camera Trapping

We conducted camera surveys using 160 passive infrared-triggered remote cameras (e.g., (Browning Recon Force, Model BTC-7FHD, Prometheus Group, LLC Birmingham, Alabama, USA) for 3-month seasonal sampling intervals; seasons were defined by dividing the year into biologically meaningful periods that approximate changes in phenology and bobcat reproductive ecology (Nielsen and Woolf 2002*a*). We defined the breeding and parturition–kitten rearing seasons as 1 November–30 April and 1 May–31 October, respectively (Nielsen and Woolf 2002*a*). Prior to camera deployment, we divided our study site into 9 km^2 camera survey units (i.e., approximate diameter of smallest recorded home range size for a female bobcat in southern Illinois; Nielsen and Woolf 2001). We generated centroid locations for each camera survey unit and randomly selected 60–80 units (i.e., 15–20 units per county) that contained ≥50% forest cover for camera surveying. We navigated to camera station (centroid) locations and placed two cameras on both sides of known travel corridors. In cases when centroid locations were not located in optimal (forested) habitat, we adjusted them by placing cameras in or along the edge of the nearest forested habitat.

We placed camera stations at a mean height of 0.3 m above ground and fastened them to sturdy vegetation or wooden surveyor stakes (61 cm × 7.62 cm) at a 4.6 m spacing staggered by 4.6 m (Fig. 2) which increased the chances of obtaining at least one high quality image of both sides of the individual (Kelly et al. 2008, Rovero et al. 2013, Foster and Harmsen 2012, Thornton and Pekins 2015). We hung visual attractants (i.e., compact discs) from vegetation out of the field of view (Nielsen and McCollough 2009) of camera stations. A capture event consisted of a photograph of a uniquely identifiable bobcat at ≥1 camera at a station. Individual bobcats were identified by comparing bobcat photos using standard pelt pattern protocol outlined by Heilbrun et al. (2003). When applicable, we also used capture photos of previously captured and radiocollared bobcats (n = 13) to aid in uniquely identifying individuals photocaptured at camera stations. We calculated total number of bobcat events and total number of photographs for bobcats as measures of trap success (calculated number of bobcat events per 100 trap nights; Kelly et al. 2008). We defined detection efficiency of each event as the number of camera stations that photograph ≥1 bobcat divided by the total number of active stations (Larrucea et al. 2007).

Camera Density

We tested the potential effect of camera density on number of bobcat photo-capture and recaptures using a modification of the protocol described previously by Larrucea et al. (2007). We evaluated six densities (1, 2, 4, 6, 8, and 10 camera stations per 9 km^2) by placing grids of the appropriate size over camera survey units; we defined 1–2 cameras stations/9km^2 as low density, 4–6 cameras/9km^2 as moderate density, and 8–10 camera stations/9 km^2 as high density. We determined locations of camera stations by placing 25 0.36-km^2 (600 × 600-m) square grids over the 9 km^2 camera survey units (Fig. 2) and placing cameras as close to the center of each grid along the nearest travel corridor (Larrucea et al. 2007). Given the limited availability of forested cover (25%) throughout our study site, we selected 0.36-km^2 grids to maximize the likelihood of deploying camera stations in high-quality (>50% forested cover) habitat. Additionally, we increased the likelihood of capturing and recapturing bobcats by deploying camera stations within known bobcat (i.e., radio-collared) home ranges. We conducted camera density evaluations during 2 30-day sampling intervals during 15 May–15 June 2016 and 20 April–20 May 2017. All cameras were operational 24 hours per day set on rapid-fire mode (3 shot burst) with a delay of 1 minute (Foster and Harmsen 2012, Rich et al. 2014).

Data Analyses

We used Bayesian analysis to develop a spatial capture-recapture (SCR) model for estimating bobcat density across our study site per the recommendations of Royle et al. (2011). Unlike classical closed-population capture-recapture models, SCR models formally relate encounters of individuals to where individuals spend time over trapping intervals (Royle et al. 2011). Thus, individuals that center activity patterns across a defined area over a given period of time should be expected to encounter a trap as a function of the distance between that animal's activity center and the trap (Royle et al. 2010). Functionally, SCR models are essentially standard, closed population models augmented by a spatial random effect that describes the juxtaposition of individuals with the trap array (Royle et al. 2011). We conducted Bayesian analyses using Markov-Chain Monte Carlo (MCMC) simulations over the region where camera station locations were distributed (i.e., state-space of the point process; Royle et al. 2011). We followed the procedures of Royle et al. (2011) to define the continuous state space by overlaying the trap array on a square region extending 20 km beyond camera traps in each cardinal direction. We scaled the state-space by defining it near the origin and fit models for a range of choices of the square state-space based on buffers from 5 to 20 km (Royle et al. 2014). We modified the wolvSCR0 function provided in the R package scrbook and fit models in JAGS using data augmentation with M = 100–150 individuals, a state-space buffer of 1 standardized unit, three MCMC chains each of 12,000 total iterations, and discarded the first 2000 as burn-ins (Royle et al. 2014). To meet basic assumptions of closed populations, we limited our SCR analysis to data collected during the 2017 breeding season (1 February 2017 to 18 April 2017).

We used one factor analysis of variance and simple correlation analyses to evaluate potential associations between camera density and photo-capture and recapture rates of bobcats. We used Tukey's HSD post-hoc analyses to test for differences in capture and recapture rates between camera densities. We conducted all analyses using Program R (R Core Team 2015); statistical tests were conducted at $\alpha = 0.05$.

RESULTS

Spatial Capture-Recapture Model

We deployed 50 camera stations in a 1,499 km^2 area over a 77-day period from 1 February–18 April 2017. Mean operational time of cameras was 52 days (range = 32 to 67 days). We captured 23 uniquely identifiable bobcats 115 times and recaptured these same individuals 92 times. We photographed bobcats at 36 of 50 (72%) camera stations. Due to unidentifiable features of bobcats at 2 camera stations and theft of cameras at one station, we used 34 camera stations in analyses. Individual encounter frequencies ranged from 4 individual captured 1 time in a single trap to 1 individual captured 17 times in 5 different traps (Table 1). For the 5-km continuous state-space model, our analysis revealed a slight effect on the posterior distribution of density because the state-space is not sufficiently large (Table 2). However, posterior summary statistics for the 10-km, 15-km, and 20-km continuous state-space models were similar (Table 2). Using the posterior mean from the state-space based on the 10-km buffer, the point estimate of bobcat density was 1.44 individuals per 100 km^2 (Table 2). Densities ranged from 1.44–1.57 bobcats per 100 km^2 with a 95% posterior interval of 1.07 to 1.90 (Tables 2, 3). Our estimates of R-hat was 1.00 for all chains, indicating good model convergence within and between chains.

Camera Density Capture Probabilities

We deployed 31 camera stations during two sampling intervals (15 May to 15 Jun 2016, 20 Apr to 20 May 2017) over 1,800 trap nights. Our analyses revealed that effects of camera density on bobcat detection probability was marginally significant ($F_{2,3}$ = 7.33, P = 0.07, R^2 = 0.80) and most evident between low and moderate camera station densities; probability of detection was similar (P = 0.27) between moderate and high camera densities. Similarly, probability of detecting bobcats was similar (P = 0.29) between low and high camera densities; maximum detection was associated with moderate camera densities (Table 4, Fig. 3). In addition, the number of individual bobcats detected varied ($F_{2,3}$ = 9.93, P = 0.04) with camera density; moderate and high camera densities yielded greater ($P \leq 0.05$) numbers of individuals than lower camera densities, though were similar (P = 0.94) between moderate and higher camera densities; we detected no more than 4 individual bobcats at any 1 camera station (Table 4). Although we documented no differences ($F_{2,3}$ = 4.21, P = 0.14) in recapture rates between low and high camera densities, correlation analyses suggested positive associations (R^2 = 0.71) between recapture rates and increasing camera densities (Fig. 4).

DISCUSSION

Spatial capture-recapture model

We evaluated the utility of SCR continuous state-space models for estimating density of bobcats in fragmented Midwestern landscapes. Our analyses revealed variation in density estimates and associated model parameters between 5-km buffers and larger buffers around camera trap arrays. However, estimated densities varied little between the 10-km and 20-km buffers around trap arrays, which suggests that larger grids appeared to be an operational compromise that accounted for movement of individuals into and out of the continuous state-space while eliminating the probability of excluding individuals whose activity centers (i.e., home ranges) were located outside camera survey units. Thus, larger grids (i.e., ≥10 km buffers around trapping arrays) appeared to be an operational compromise that yielded adequate estimates of density (Royle et al. 2011).

By using SCR models for estimating density, we avoided several key limitations inherent in non-spatial models for species that are elusive and exist at low population densities (Royle et al. 2011). First, logistical constraints of conducting camera trapping surveys across landscapes that are overwhelmingly in private ownership increased the difficulty of ensuring the number of trap sessions among camera sites were the same. Additionally, non-spatial models do not account for spatial organization of individuals in a population or the observation mechanism (e.g., trap locations), typically resort to a focus on models of encounter probability (i.e., encounter or not), and thus make it increasingly difficult to determine how to condense and subsequently standardize trap-specific encounter histories (Royle et al. 2011, 2014). Further, excess recapture events (i.e., bobcats captured multiple times at a single camera station in a session) often are discarded or pooled and information about the encounter process is lost (Royle et al. 2011). Consequently, pooling data from a trap array into discrete survey intervals to construct non-spatial encounter histories is not intuitive, particularly when trap orientation is staggered and length of time that traps are deployed is variable (Royle et al. 2011). Nevertheless, trapping sessions of equal length and pooling of data were unnecessary for estimating density of bobcats using SCR models because they are based on trap-level encounters of individuals and incorporate animal movements directly into the model. Provided there is sufficient data across some range of animal distances moved, SCR models are capable of making predictions across distances even when these are latent or extend beyond the extent of the trap array (Royle et al. 2011, 2014).

The current body of CR literature has long recognized the importance of adequate trap spacing and overall configuration of the trapping array (Royle et al. 2014). A corollary based on the need to obtain information about home range size (Dice 1938, 1941) from the trap array is that trap spacing should detect as many individuals as possible, yet maximize the likelihood of capturing individuals at multiple trap sites (Royle et al. 2014). Thus, study designs should seek to obtain a large sample size (i.e., the number of individuals captured) and a large number of spatial recaptures (Royle et al. 2014). Traditional CR models require that all individuals have a probability of > 0 of being captured, and that trap arrays contain no "holes" large enough to partially or completely encompass an animal's home range (Otis et al. 1978). Spatial study design requirements for SCR models do not require deploying regularly-spaced survey grids, and thus relaxes the "no holes" assumption of traditional CR (Royle et al. 2014). Nevertheless, SCR study designs induce some strong restrictions on the need for relatively consistent spatial coverage of the survey area of interest, which often are achieved by dividing study areas into grid cells that approximate the average (or smallest) home range size for the study species and placing ≥1 camera trap within the cell (Wallace et al. 2003, Royle et al. 2014). While we recognize the size of our camera survey units may not have been sufficiently large to ensure that all individuals had some probability of being captured (Otis et al. 1978), we followed the recommendation of previous researchers by using regional estimates of bobcat home range size into our study design, and thus optimize trap spacing and configuration of our trapping array (Wallace et al. 2003, Dillon and Kelly 2007). Achieving consistent coverage of trapping arrays will remain challenging in field situations due to spatial heterogeneity in individual capture probabilities attributed to logistical constraints, local environmental conditions, and spatial configuration of animal home ranges near the borders of trap arrays across large study areas (Otis et al. 1978, Royle et al. 2014). Nevertheless, our results indicated that despite the use of a non-systematic trapping array, obtaining sufficiently large numbers of spatially dispersed capture and recapture events of bobcats across fragmented landscapes is achievable.

Lastly and inherent in all closed population models is the assumption of demographic closure (i.e., no permanent movement into our out of a population) during the trapping period, which in SCR models is accounted for in the static nature of animal activity centers (Royle et al.

2011). Our trapping period occurred over a relatively short (i.e., 77 days) duration and core area estimates for the majority (70%) our radiocollared animals (n = 13) indicated no closure assumption violations. To the extent that non-closure was present and associated with variability in home range use by transients, such heterogeneity could be modeled as an individual-specific encounter probability that accounts for intraspecific variation in home range size (Royle et al. 2011). Additionally, further extensions of SCR models that account for intra-sexual variation in home range size, movements between activity centers, or home range shifts due to a range of biological phenomena may account for heterogeneity in individual capture probabilities (Royle et al. 2011), and thus improve density estimates of bobcats across Midwestern landscapes.

Camera Density Capture Probabilities

A primary objective of our study was to optimize camera stations to maximize photo-capture and recapture rates of individual bobcats to aid in density estimation. The importance of camera placement has long been debated in the capture-recapture literature, most notably strategically placing traps at known animal activity centers versus systematically placing traps across a trapping grid (Karanth and Nichols 1998, Larrucea et al. 2007, Royle et al. 2014). These two considerations form a trade-off in designing capture-recapture studies using camera trapping. On the one hand, maximizing recapture events may be aided by having a high density of traps close together and within known activity centers, which may result in the capture of few unique individuals. Conversely, deploying a lower density of traps across a larger spatial extent in systematic or grid designs should maximize the greatest number of unique individuals, though may yield few spatial recaptures. The relationship between photo-capture and recapture rates and camera density revealed by our analysis suggested that of the total camera stations deployed, 31% photo-captured bobcats, whereas nearly 70% of cameras placed across survey grids did not detect individuals. However, no camera traps across the range of densities we evaluated detected more than 4 individual bobcats, despite as many as 17 photo-captures of a single individual at 5 of 163 (3%) camera stations. Further, our analyses indicated a non-linear trend in probability of detecting bobcats marked by maximum photo-capture rates at moderate camera densities (i.e. 4–6 per 9 km^2; Fig. 3). Low camera densities were insufficient for maximizing detection of uniquely identifiable individuals, and high camera densities (i.e., 8–10 per 9 km^2) were no more likely to detect new individuals than moderate densities of cameras (Fig. 4). These results support the continued deployment of grid-based strategies across fragmented Midwestern landscape and the potential repositioning of unproductive cameras to more productive areas within the survey grid (Larrucea et al. 2007). If the numbers of cameras is limited, camera efficiency may be enhanced by using moderate densities of cameras (0.44 to 0.67 cameras/km^2) in adjacent survey units to maximize photo-capture rates or identify individual bobcats across fragmented landscapes.

Our analyses indicated that size of camera survey units and camera spacing should be considered to ensure that all individuals in the study area have a probability >0 of being captured, which means trap arrays must not contain “holes” large enough to contain an animal’s entire home range (Otis et al. 1978). If an animal’s home range lies within areas with an insufficient density of cameras, then it may have a different probability of being captured than an individual whose home range has a higher density of cameras. Hence, trap spacing should be on the same order as the radius of a typical home range (Dillon and Kelly 2007) to ensure consistent coverage of the area of interest. Our study design followed recommendations by Wallace et al. (2003), whereby we divided the study area into grid cells that represented the smallest home range size of female bobcats in southern Illinois (Nielsen and Woolf 2001) and subsequent placement of a trap within each cell. Regardless of whether the trap spacing results in holes in the trapping array or not, the problem of spatial heterogeneity in capture probability will still exist because individuals with home ranges near the borders of the trap array will have a different probability of being captured than individuals that spend all their time within the trap array (Royle et al. 2014). Nevertheless, our analyses suggest that deploying moderate densities of cameras throughout trapping arrays may minimize potential effects of heterogeneity in individual capture probabilities and improve precision in density estimates of bobcats across fragmented Midwestern landscapes.

MANAGEMENT IMPLICATIONS

We provide the first application of SCR models to estimate density of bobcats across the species' geographic range. We have shown that variation in the state-space extending beyond trap arrays affect bobcat density estimates and should be sufficiently large to minimize encountering individuals with activity centers (i.e., home ranges) beyond the state-space boundary. Increased size of home ranges of bobcats across Midwestern landscapes may necessitate the use of relatively coarser survey grids in SCR models to account for frequent movements to and from the state space or whose core areas are positioned beyond camera survey unit boundaries. Similarly, when photo-capture and recapture rates are a function of camera density, modifying camera trapping techniques by deploying moderate camera densities or repositioning cameras within survey grids may improve capture success in low density bobcat populations throughout Midwestern landscapes.

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Table 1. Individual capture frequencies for bobcats captured in camera traps in west-central Illinois, 1 February to 18 April 2017. Rows index unique trap frequencies and columns depict total number of captures (e.g., 4 individuals captured one time in one trap vs. 1 individual captured 17 times in 5 different traps).

	No. captures									
No. traps	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**9**	**12**	**17**
1	4	3	0	1	0	0	0	0	0	0
2	0	0	3	0	2	1	2	0	0	0
3	0	0	0	1	0	0	0	0	0	0
4	0	0	0	0	0	1	2	0	0	0
5	0	0	0	0	0	0	0	0	0	1
6	0	0	0	0	0	0	0	1	1	0

Table 2. Posterior summaries of spatial capture-recapture model parameters for bobcat camera trapping data from west-central Illinois from 1 February to 18 April 2017, using state-space buffers from 5 to 20 kilometers. Analyses were based on 3 chains, 12,000 iterations, 2000 burn-in, for a total of 30,000 posterior samples. σ is a scale parameter related to $\alpha 1$ by $\alpha 1 = 1(2\sigma^2)$, as the radius of the bivariate normal model of space usage. N. eff = effective sample size given all chains and accounts for autocorrelation in the chain. N = population size for the prescribed state-space, and D is the density per 100 km^2.

	σ			N			D		
Buffer	**Mean**	**SD**	**N.eff**	**Mean**	**SD**	**N.eff**	**Mean**	**SD**	**N.eff**
5	4.281	0.311	9908	30.882	3.492	6921	0.157	0.018	6921
10	4.260	0.318	1549	43.163	6.528	16076	0.144	0.022	16076
15	4.240	0.312	948	61.192	10.563	1093	0.145	0.025	1093
20	4.230	0.308	1450	82.445	15.186	4481	0.146	0.027	4481

Table 3. Posterior summaries of spatial capture-recapture model parameters for bobcat camera trapping data from west-central Illinois, 1 February to 18 April 2017. Analyses were conducted with a trap array centered in a state-space with a 10 kilometer square buffer. N = population size for the prescribed state-space, D = the density per 100 km^2, σ is a scale parameter related to $\alpha1$ by $\alpha1 = 1(2\sigma^2)$, as the radius of the bivariate normal model of space usage. p_0 is the baseline encounter rate and Ψ is an estimate of the percent occupancy by an animal in space. Rhat is a measure of variably within and between chains, and converges on 1 as chains are allowed to run for an infinite number of draws.

Parameter	**Mean**	**SD**	**2.5%**	**50%**	**97.5%**	**Rhat**
N	43.163	6.528	32.000	43.000	57.000	1.000
D	0.144	0.022	0.107	0.144	0.190	1.000
α_1	0.028	0.004	0.020	0.028	0.036	1.002
p_0	0.026	0.004	0.019	0.026	0.035	1.001
σ	4.260	0.318	3.714	4.234	4.961	1.003
Ψ	0.433	0.080	0.288	0.429	0.601	1.000

Table 4. Effects of camera density on probability of capture and recapture of bobcats in west-central Illinois, 2016–2017.

Camera Density[a]	# of photos[b]	# of individuals bobcats[c]	# of recaptures[d]	Detection rate[e]
1	0	0	0	0.00
2	6	2	0	0.25
4	71	4	7	0.50
6	81	4	10	0.58
8	48	4	5	0.31
10	78	4	13	0.35

[a]Number of cameras per 9 km^2.

[b]Total number of bobcat photos.

[c]Number of uniquely identifiable individuals.

[d]Total number of bobcat recapture events.

[e]Total number of camera stations/number of stations that detected ≥1 bobcat.

List of Figures:

Figure 1. Bobcat (*Lynx rufus*) study areas were located in Fulton, Hancock, McDonough, and Schuyler counties (inset) of west-central Illinois, 2015–2017. Thin black lines delineated county boundaries.

Figure 2. Bobcat camera station locations were selected by overlaying 9 km^2 grids (thick black lines) over aerial imagery in each of four counties (i.e., Fulton, Hancock, McDonough, Schuyler) and subdividing them into 0.36 km^2 grids (thin black lines within 9 km^2 grids). Centroid locations (white circles) were generated and camera station units were randomly selected based on availability of suitable bobcat habitat (i.e., ≥50% forested cover).

Figure 3. Probability of detection of bobcats as a function of increasing density (# per 9 km^2) of camera stations deployed across west-central Illinois, 2016–2017.

Figure 4. Relationship between the probabilities of recapturing bobcats as a function of increasing camera density (# per 9 km^2) across west-central Illinois, 2016–2017.

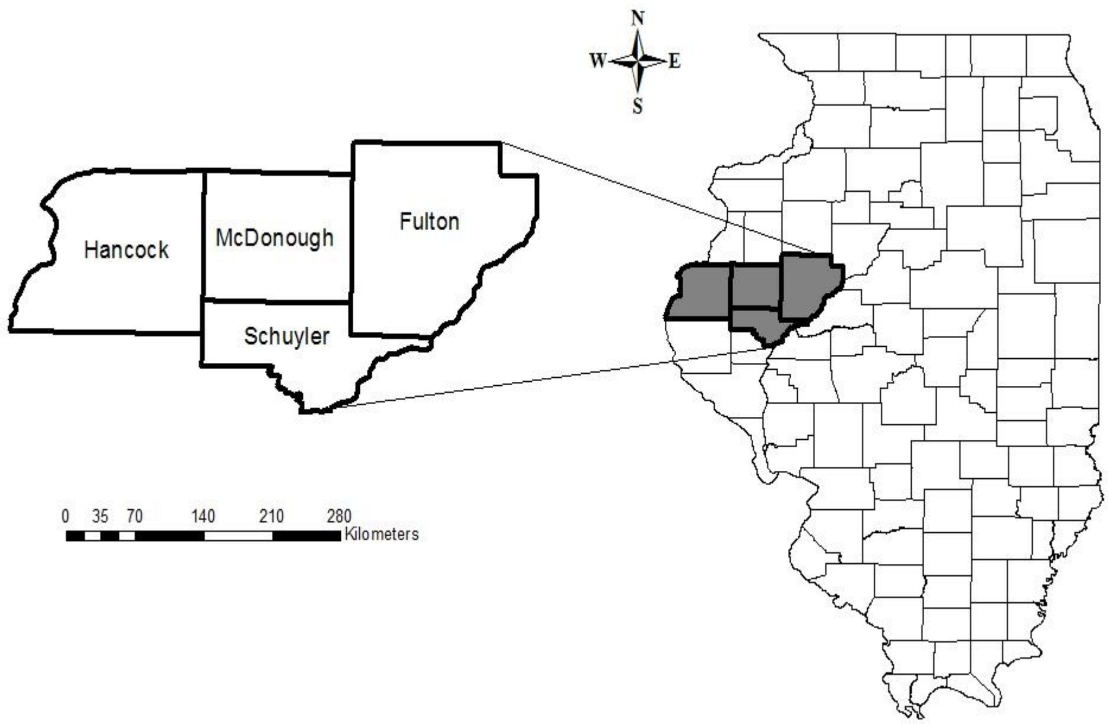

N
W
E
S
Hancock
McDonough
Fulton
Schuyler
0 35 70 140 210 280
Kilometers

Figure 1.

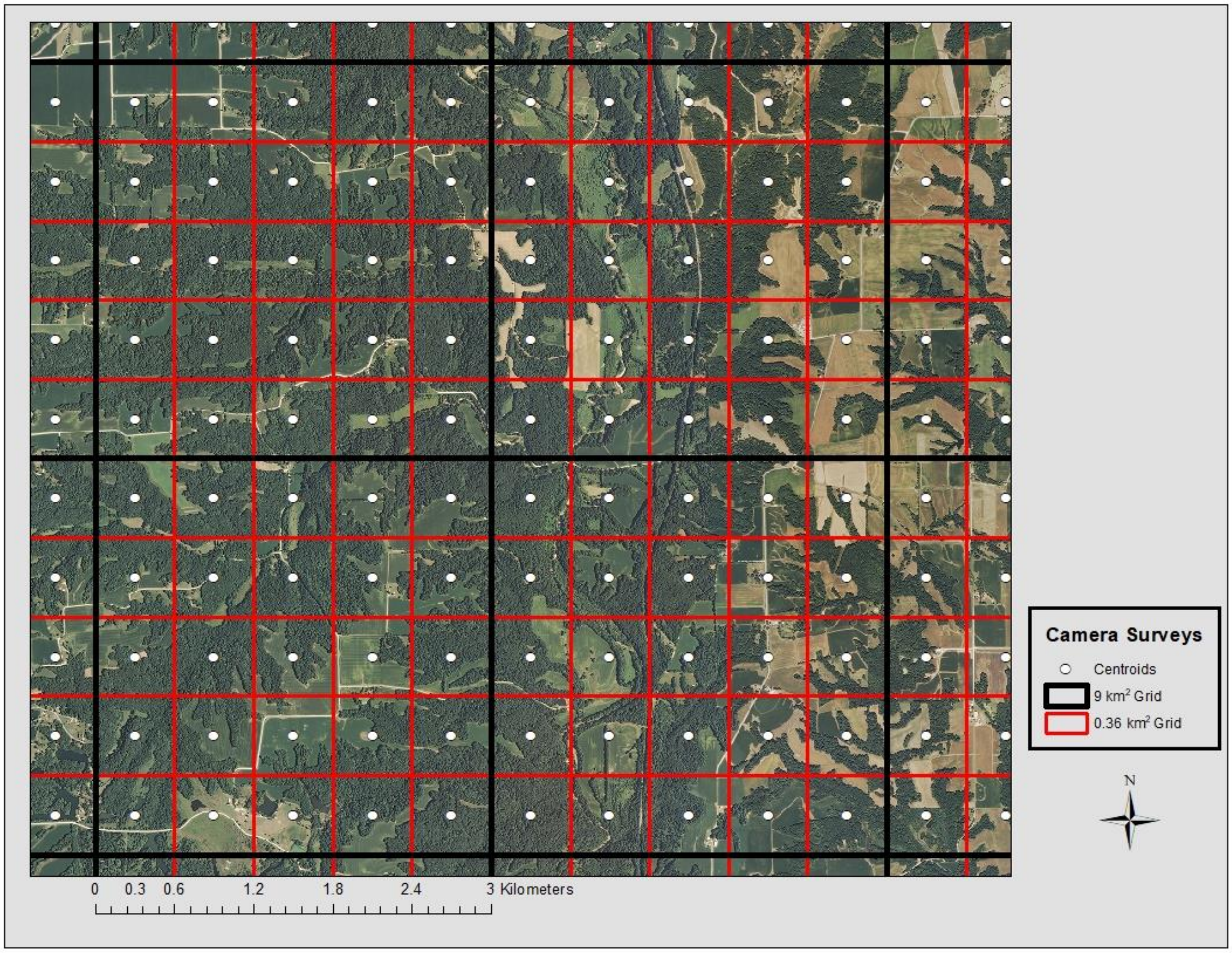

Camera Surveys
Centroids
9 km2 Grid
0.36 km2 Grid
N
0 0.3 0.6 1.2 1.8 2.4 3 Kilometers

Figure 2.

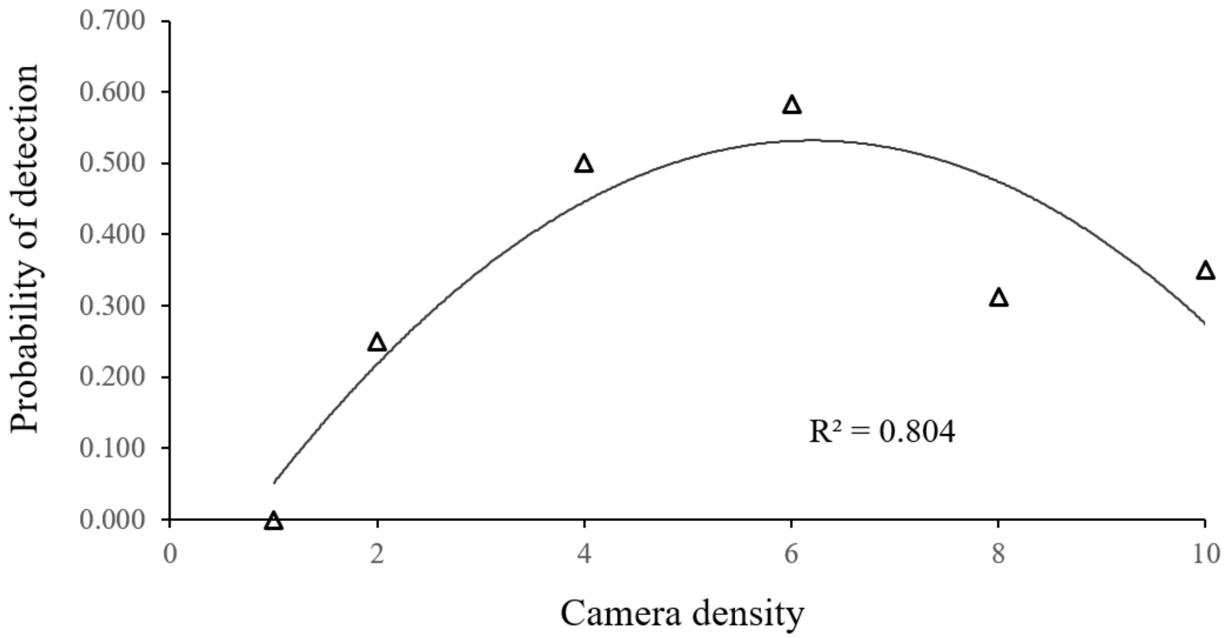
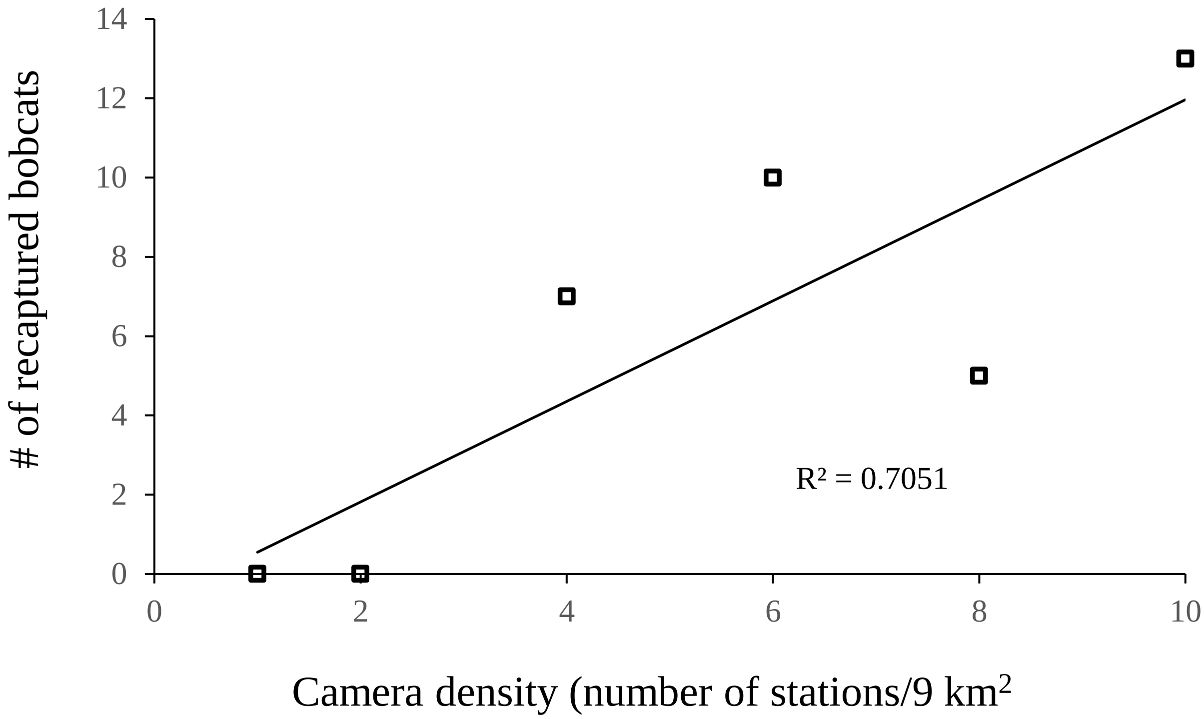

0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
Probability of detection
R² = 0.804
0
2
4
6
8
10
Camera density

Figure 3.



14
12
10
8
6
4
2
0
# of recaptured bobcats
R² = 0.7051
0
2
4
6
8
10
Camera density (number of stations/9 km2

Figure 4.

Objectives: *3) Estimating home ranges of bobcats inhabiting west-central Illinois and relationships with detection by camera traps by 30 June 2017.*

4) Recommending efficient protocols for estimating density of bobcats across west-central Illinois by 30 June 2017.

INTRODUCTION

Historically, bobcats (*Lynx rufus*) were widespread across prairie woodland complexes of the Midwest, though were considered rare throughout the Corn Belt region during the century (1840s–1940s) following European settlement (Deems and Pursley 1978, Dinsmore 1994). The extirpation of bobcats from this region has been attributed primarily to unregulated harvest and conversion of land to row crop agriculture (Hamilton and Fox 1987, Rolley 1987, Woolf and Hubert 1998). In 1977, the Illinois Department of Natural Resources (IDNR) listed bobcats as a state threatened species following initial protection under the Wildlife Protection Code of 1971 (Woolf et al. 2002). Around the same time, protective measures also were implemented in Iowa (Endangered in 1977), Indiana (Endangered in 1969), and Ohio (Endangered in 1974), USA (Tucker et al. 2008). Since then, periodic sightings of bobcats throughout Illinois have occurred, though remained relatively low through the 1980s (Woolf and Hubert 1988). By the early 1990s, the number of bobcat sightings increased dramatically across the state (99 of 102 counties), thereby suggesting that population abundance likely increased throughout the 1990s and that their current classification as threatened was no longer warranted (Woolf et al. 2000). The increase of bobcats in Illinois is consistent with other areas across the Midwest (Tucker et al. 2008). Like other populations of large predators that inhabit altered landscapes (Maehr et al. 2001, Nielsen and Woolf 2001, Sunquist and Sunquist 2001), there is considerable interest in understanding the response of bobcats to habitat characteristics (e.g., fragmentation, configuration) that are enabling them to expand their range throughout Midwestern landscapes (Tucker et al. 2008).

Illinois is well known for having an agriculturally-dominated landscape consisting of >50% annual row crops (IDNR 2005). Preferred bobcat habitat features such as forest (Lovallo and Anderson 1996, Chamberlain et al. 2003, Preuss and Gehring 2007) and grassland (Kamler and Gipson 2000) occur in a mosaic of fragmented patches and corridors throughout Illinois that may affect bobcat population dynamics by limiting movement, contributing to seasonal shifts in home range boundaries, and altering fine-scale patterns of habitat selection (Sunquist and Sunquist 2001). Previous researchers have hypothesized that the enrollment of land into the Conservation Reserve Program (CRP) may have increased availability of habitat to bobcats and their primary prey, and thus may be important in enabling the long-term persistence of bobcat populations in Midwestern landscapes (Tucker et al. 2008). In landscapes dominated by intensive row crop agriculture, it also may be reasonable to suggest that croplands also may be influencing the population ecology of bobcats across fragmented Midwestern landscapes.

Home range estimates can be used as a rudimentary way to estimate density in various landscapes, which may aid in predicting expansion of bobcats into agriculturally dominated landscapes. Although home range use by bobcats have been conducted in fragmented Midwestern landscapes (Lovallo and Anderson 1996, Kamler and Gibson 2000, Nielsen and Woolf 2001, Preuss et al. 2007, Tucker et al. 2008), it may be inappropriate to apply findings from previous studies to areas with markedly different landscapes. Thus, the objective of our study was to evaluate home range size of bobcats in an agriculturally-dominated landscape of west-central Illinois. We hypothesized that relative to other Midwestern landscapes characterized by a lower availability of row crop agriculture, home range sizes in west-central

Illinois would be relatively larger and influenced by the area and configuration of forest and cropland habitats. A more complete assessment of spatial distribution and habitat selection patterns by bobcats will inform harvest decisions about management programs and aid in the development of approaches for monitoring and estimating abundance of bobcats throughout Illinois.

METHODS

Capture and handling

We trapped bobcats during 2 consecutive winters between 1 January 2016 and 9 March 2017 with Camtrip cage traps (guillotine door, frameless wire mesh box traps [~25.4 × 48.26 × 91.44 cm]; Camtrip cages, Barstow, CA) and MB-550 offset modified foot hold traps (Minnesota trapping products, Pennock, MN). Additionally, we handled individuals incidentally live-trapped by licensed private trappers if they were uninjured and within the boundaries of our study area. We immobilized trapped bobcats with an intramuscular injection with a combination of ketamine hydrochloride (HCL; 10 mg/kg) and xylazine HCl (1.5 mg/kg; Kreeger and Franzmann 1996). We sexed, weighed, recorded morphometric data, and estimated age of bobcats based on body mass (e.g., animals > 5 kg will be classified as adults [≥ 2 yrs.], individuals < 5 kg will be considered juveniles; Nielsen et al. 2001, 2002*a*, 2002*b*). We fitted each bobcat (≥ 5 kg) uniquely numbered ear tags (Standard Rototag: https://www.enasco.com/product) and a very high frequency radiocollar (150–151 MHz; Telonics, Mesa, AZ; Model 315-S6A) equipped with mortality sensors. In all cases, we ensured that radiocollars weighed ≤ 5% of the individual's body weight. Prior to release, we administered an intramuscular injection of tolazoline HCl (4 mg/kg) as an antagonist to xylazine HCl (Kreeger and Franzmann 1996) to aid in recover time. Capture and handling protocols were approved by the Institutional Animal Care and Use Committee at Western Illinois University (approval number 15-09) and followed guidelines for the care and use of animals approved by the American Society of Mammalogists (Sikes et al. 2016).

Radio telemetry

We used standard ground telemetry techniques to monitor movement of bobcats on average once per week from January 2016 through May 2017, after which field work was terminated. We rotated telemetry tracking efforts so that we collected locations throughout the entire 24 hr period, so we captured habitats for both resting and foraging behavior. We used standard ground radio telemetry techniques to track bobcats (White and Garrott 1990). We used radio telemetry, capture, and visual locations to determine point locations of radiocollared bobcats. To the extent possible, we minimize time between first and last bearings (i.e., ≤20 min; Nielsen and Woolf 2001) when locating animals to reduce the likelihood of animal movement, and thus bias in location data. Additionally, we collected locations of individuals ≥20 hr apart (Nielsen and Woolf 2001) to minimize temporal bias in home range estimates. We estimated animal locations using Program LOCATE III using the maximum likelihood estimator (Nams 1990) with a minimum of 2 azimuths for each location, and to calculate bearing error and home range error polygons (Nielsen and Woolf 2001).

Home range and Core Area Estimation

We entered locations into a geographic information system, and analyze them to determine home range use of adult resident bobcats. We calculated home ranges and core areas using an adaptive kernel estimator with least squares cross validation (Worton 1989, Kie et al. 1996, Seaman et al. 1999) in the Animal Movements extension (Hooge and Eichenlaub 1997) for ArcView. We used a 95% utilization distribution (UD) to calculate home ranges and a 50% UD to calculate core areas (Powell 2000, Tucker et al. 2008). We generated home-range and core area estimates using an ad hoc smoothing parameter by choosing the smallest increment of the reference bandwidth (h_{ref}) that results in a contiguous 95% kernel home range (i.e., $h_{ad\ hoc} = 0.9 \times h_{ref}$, $0.8 \times h_{ref}$, etc; Kie 2013). Kernel estimators are nonparametric and thus are not based on an assumption that the data conform to specified distribution parameters (Seaman et al. 1999). Due to limited sample sizes, we limited our analyses to annual home range calculations using a minimum of 20 locations (Seaman et al. 1999) for each radio-collared bobcat. To avoid potential biases in the number of locations collected between individuals and seasons, we attempted to distribute telemetry location efforts evenly among individuals, both spatially (across treatment plots) and temporally (seasonally). We considered a bobcat a resident if it did not make a permanent one-way movement outside the boundary of its previously established home or natal range (Kamler and Gipson 2000, Tucker et al. 2008). To approximate a normal distribution, we log transformed all 95% and 50% UDs (Ramsey and Schafer 2002, Tucker et al. 2008).

Data analysis

To evaluate potential effects of intrinsic (i.e., sex) and habitat characteristics on bobcat home range use, we created a 3,770-m circular analysis regions around geometric centers of each individual (Kie et al. 2002, Bowyer and Kie 2006); the associated circular analysis region (43.22 km^2) comprised the land area that was the approximate mean 95% home range size of adult female bobcats across our four county study site. Further, this area encompassed all 50% core areas of male bobcats, thus was likely reflective of the highest quality habitat across our study site. To determine habitat characteristics associated with each individual, we overlaid circular analysis regions on the 2011 National Land Cover Data set (NLCD) and calculated habitat composition (% composition of each buffer) using Geospatial Modeling Environment (http://www.spatialecology.com/gme) in ArcGIS 10.3 (Esri, Inc., Redlands, California, USA). We re-classified land cover data into 5 categories; grassland/pasture-hay/shrubs, forested cover, cultivated crops, wetlands, and open water. For a detailed description of land cover categories, see the NLCD website (http://www.mrlc. gov/nlcd06_ leg.php). We used FRAGSTATS Version 4.2 to calculate landscape and class-level metrics associated with each buffered area by county (McGarigal et al. 2002).

We selected the intrinsic and habitat factors (Table 5) that we considered biologically meaningful to bobcat ecology. Further, these variables also have been identified as important factors influencing bobcat home range use in agriculturally dominated landscapes across the Midwest (Tucker et al. 2008). We broadly defined habitat variables as a) percent cover (percent of landscape comprised of habitat cover type), b) patch density (number of patches/100 ha of the cover type), c) shape index (i.e., average departure of patches from maximum compaction), and d) landscape shape index (i.e., standardized measure of the edge for all cover type patches), e) percent of patch mixing between habitat classes, and f) percent of patch aggregation for specified habitat classes (McGarigal et al. 2002). Because of the small number of bobcats available for home range analyses, we limited our model set to single parameter models evaluating main effects only (Table 6).

We used 1-way analysis of variance (ANOVA) limited to main effects to evaluate potential effects of sex and habitat parameters on 95% and 50% home range use by bobcats. Additionally, we used 1-way ANOVA to test for intersexual differences in body mass. We generated Type III sums of squares in ANOVA models to account for our use of cross-classification designs with unbalanced data (SAS Institute Inc. 2008). We conducted statistical analyses using Program R (R Core Team 2015).

RESULTS AND DISCUSSION

We live trapped 22 bobcats (13 male, 9 female) between 1 July 2015 and 30 Jun 2017. We collected 347 locations from those individuals from 3 Jan 2016 to 1 Jun 2017. Mean body mass of adults at capture varied ($F_{1,20} = 23.28$, $P = 0.002$) for male ($\bar{x} = 11.40$ kg, SE = 0.63, $n = 14$) and female ($\bar{x} = 7.74$ kg SE = 0.18 $n = 8$) bobcats. We censored 9 individuals from our home range analyses due to mortality ($n = 3$), lost contact ($n = 3$), dispersal ($n = 1$), and insufficient numbers of relocations ($n = 2$), we conducted home range analyses using 13 individuals. Mean annual home range and core area sizes were 98.2 km^2 (SE = 30.66) and 15.4 km^2 (SE = 4.38), respectively. We documented significant differences ($F_{1,11} = 6.82$, $P = 0.02$) in 95% home range sizes between males ($\bar{x} = 186.14$ km^2 (SE = 57.61, $n = 5$) and females ($\bar{x} = 43.22$ km^2, SE = 17.65, $n = 8$). Similarly, core area size varied ($F_{1,11} = 7.79$, $P = 0.02$) between males ($\bar{x} = 28.20$ km^2, SE = 8.07) and females ($\bar{x} = 7.41$ km^2, SE = 2.80). However, our analyses revealed no relationships ($F_{1,11} \leq 2.39$, $P \geq 0.15$) between habitat variables and home range use by bobcats; small sample sizes likely precluded our ability to detect habitat effects on patterns of space use by male and female bobcats. Nevertheless, home range estimates across our study site are the largest reported for bobcats across similarly fragmented Midwestern landscapes (Nielsen and Woof 2001, Preuss et al. 2007, Tucker et al. 2008), and to our knowledge the largest documented across the species' range. Despite uncertainty in the specific landscape factors contributing to our reported home range estimates, previous studies have noted the effects of row crop agriculture and fragmentation of perennial forests and grassland habitats on patterns of home range use by bobcats across fragmented Midwestern landscapes (Nielsen and Woolf 2001, Tucker et al. 2008).

Future research efforts will be focused on obtaining a larger sample of bobcats to further assess the effects of habitat factors on seasonal variation in annual and seasonal home range use patterns by bobcats across west-central Illinois. Our preliminary findings are important and are currently being used to guide future refinement of camera survey protocols for use in improving ongoing bobcat density estimation techniques across Illinois. To date, our findings suggest that deployment of 4–6 camera stations/9 km^2 limited to winter months is sufficient for obtaining relatively precise density estimates. However, future telemetry data aided by GPS collars will provide additional insight into fine scale habitat selection (i.e., home range use) by bobcats across our study site, thereby enabling further refinement to existing camera survey protocols.

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Table 5. A priori candidate models constructed to determine potential effects of sex and habitat variables on home range use of bobcats in west-central Illinois, USA, 2015–2017. We limited our model set to main effects (i.e., single parameter models) due to small sample sizes.

Variable name	**K**	**Description**
Sex	1	Sex of captured bobcats
Patch density	1	Average patch size (ha) for all habitat patches (PD)
Largest patch index	1	Percentage of landscape comprised by largest habitat patch (LPI)
Landscape shape index	1	Standardized measure of amount of edge adjusted for size of buffered area (LSI)
Open water	1	Total open water (%, OW)
Forest	1	Total forested cover (%, FOR)
Grass/Shrub	1	Total grass and shrub cover (%, GS)
Cropland cover	1	Total cropland cover (%, CROP)
Cropland patch density	1	Density (no./100 ha) of all cropland patches (PD_CROP)
Forest patch density	1	Density (no./100 ha) of all shrub patches (PD_FOR)
Forest largest patch index	1	Percentage of landscape comprised by largest forest patch (LPI_FOR)
Crop largest patch index	1	Percentage of landscape comprised by largest patch of cropland (LPI_CROP)
Grass/Shrub mean distance	1	Mean distance between grassland/shrub patches (DIST_GS)
Forest mean distance	1	Mean distance between forest patches (DIST_FOR)
Cropland mean distance	1	Mean distance between cropland patches (DIST_CROP)
Grass/shrub patch density	1	Density (no./100 ha) of all shrub patches (PD_GS)
Cropland landscape shape index	1	Standardized measure of amount of cropland edge adjusted for size of buffered area (LSI_CROP)
Forest interspersion-juxtaposition index	1	Percent of forest patch intermixing with other habitat classes (IJI_FOR)
Grass/shrub interspersion-juxtaposition index	1	Percent of grass and shrub patch intermixing with other habitat classes (IJI_GS)
Cropland interspersion-juxtaposition index	1	Percent of cropland patch intermixing with other habitat classes (IJI_CROP)
Grass/shrub largest patch index	1	Percentage of landscape comprised by largest grassland/shrub patch (LPI_GS)
Stream density	1	Mean density (km/km^2) of streams
Road density	1	Mean density (km/km^2) of roads
Forest landscape shape index	1	Standardized measure of amount of forest edge adjusted for size of buffered area (LSI_FOR)