Habitat selection and demography of bobcats (*Lynx rufus*) in Iowa

by

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CHAPTER 1: GENERAL INTRODUCTION

Introduction

At the time of settlement bobcats were widespread in the prairie woodland complexes of the Midwest, but by the late-1970s they were considered rare throughout the Corn Belt region (Deems and Pursley 1978; Figure 1). The disappearance of bobcats from this region has been attributed primarily to an increase in the amount of land converted to agriculture and to unregulated harvest (Rolley 1987, Woolf and Hubert 1998).

Because of worldwide concern about the conservation of spotted cats, the Convention on International Trade in Endangered Species (CITES) listed the bobcat under Appendix II of the act in 1977, indicating that the species had the potential to become endangered if its trade was not regulated. In that same year the Iowa Department of Natural Resources (DNR) listed the bobcat as Endangered in the state and banned harvest of the species. For the next several years bobcats were undetectable in Iowa. These conservation actions appear to have been successful in preventing a total loss of the species because periodic reports of presence of bobcats occurred through the mid-1980 and 1990s. Since the early-1990s there has been a dramatic increase in the number of reported bobcat occurrences in the form of sightings, incidental trappings, and automobile kills. The increase in these reports warranted a change in the species status to Threatened in 2001 and then Protected in 2003. In the last several years, bobcats have been reported in approximately two-thirds of the 99 counties in Iowa (R. D. Andrews, Iowa DNR, personal communication). These reports indicate an increase in bobcat distribution and abundance, although no scientific studies have yet been conducted to determine the status of the population in the state.

Bobcats, like many predators, possess characteristics that make them particularly vulnerable to landscape change, such as long life spans, low reproductive output, large home ranges resulting in low densities, and the ability to disperse long distances (Noss et al. 1996, Sunquist and Sunquist 2001). In no part of the bobcat's range has the landscape been more altered than the agricultural Midwest. These alterations include landscapes dominated by annual row crops, a dense network of road systems, and a high proportion of rural residents. These changes contribute to the formation of highly fragmented patches of more preferred bobcat habitats such as forest (Hall and Newsom 1976, Lovallo and Anderson 1996, Nielsen and Woolf 2002, Rucker et al. 1989) and grassland (Kamler and Gipson 2000). Crooks (2002) reported that bobcat occurrence and abundance are susceptible to fragmentation, and they would not persist in areas with a high degree of fragmentation and isolation.

Although the loss of habitat due to conversion to agriculture and the fragmentation of native forests and grasslands may be at an extreme in Iowa, bobcats appear to have persisted and to now be expanding in their distribution. I hereafter refer to bobcats in Iowa as a recolonizing population, based on previously undetectable numbers and the range map published for the species in the late-1970s (Figure 1). The opportunity to study an expanding population of bobcats as they recolonize a former area of their range was a strong motivation for this study. It is unknown what ecological mechanisms are enabling bobcats to rebound from a low density presumably characteristic of Iowa.

The demography of bobcats has received a good deal of research attention in the Northwest (Gashwiler et al. 1961, Crowe 1975, Bailey 1979, Knick et al. 1985), Northeast and Northern Great Plains (Hoppe 1979, Parker and Smith 1983, Fuller et al. 1985, Gilbert and Keith 2001), and the South and Southeast (Blankenship and Swank 1979, Chamberlain et al. 1999). In the Midwest, bobcat populations have been studied by Hamilton (1982) in Missouri, Rolley (1985) in Oklahoma, Johnson and Holloran (1985) and Kamler and Gipson (2000) in Kansas, and Nielsen and Woolf (2002) in Illinois. However, none of these studies examined a population of bobcats as it was recolonizing a former area of its range, nor were they researching bobcats in as highly agricultural an area as found in Iowa. In addition, Knick et al. (1985) emphasized the need for regional management plans for bobcats because of the variation he found in the dynamics between populations.

My research took place in south-central Iowa, and the Iowa DNR Chariton Research Station was used as the center of operations. My research was conducted as part of a larger study on the landscape and population ecology of bobcats being carried out by Iowa State University and the Iowa DNR.

My objectives were to (1) determine bobcat habitat use and selection in an agriculturally-dominated landscape where large contiguous blocks of preferred habitat (e.g. forest and grassland) may be unavailable, (2) determine the population demography of bobcats, including reproduction and survival, and (3) use these region specific demographic parameters to develop a population projection model whereby population growth may be estimated. It is my intent that these findings will equip managers with an understanding of the mechanisms underlying the recolonization of bobcats in the Midwest, as well as to establish the current status of bobcats in Iowa.

Thesis organization

This thesis consists of a general introduction (Chapter 1), two manuscripts written with the intent of submission to the Journal of Wildlife Management (Chapters 2-3), and a general conclusion (Chapter 4). This thesis was written by Stephanie A. Koehler and edited by W. R. Clark. Literature cited in Chapters 1 and 4 are listed at the end of Chapter 4.

Figure 1. Distribution of bobcats in Canada and the United States during 1976. Figure taken from Deems and Pursley (1978).

CHAPTER 2: HABITAT USE AND SELECTION BY BOBCATS (*Lynx rufus*) IN THE FRAGMENTED LANDSCAPE OF SOUTH-CENTRAL IOWA

A paper to be submitted to the Journal of Wildlife Management

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Abstract: Since the late-1970s bobcats have been rare throughout the Corn Belt region, their disappearance attributed to habitat loss and to unregulated harvest. Recently, reports of bobcat occurrences have been increasing in Iowa, although biologists do not know the mechanisms enabling them to recolonize this highly fragmented landscape. We determined space use and habitat selection of bobcats by radio-collaring 44 bobcats across 9 counties in south-central Iowa during 2003-2005. We triangulated 10,023 locations and recovered an additional 1,399 3-D locations from GPS collars. We used a Fixed-Kernel estimator to calculate 95% utilization distributions (UD) for home ranges and 50% UDs for cores. Annual home range size of males (56.36 ± 7.06 km^2) was consistently larger than that of females (20.16 ± 2.18 km^2). Females used smaller home ranges during April-September when they were with kittens (15.64 ± 2.25 km^2), as compared to October-March (26.30 ± 4.03 km^2), whereas home ranges of males did not differ between seasons. Similarly, core size of males (8.75 ± 1.19) was larger than that of females (2.26 ± 0.25), and females used significantly smaller cores in April-September (1.66 ± 0.25) as compared to October-March (3.09 ± 0.49) while males did not. Compositional analysis indicated habitat selection was occurring at both landscape and local scales. Forest habitat was ranked higher than all other habitat classes, at all scales, for females and males. Standardized habitat selection ratios illustrate that female and male bobcats were selecting forest habitat about twice as frequently as any other habitat class, including grassland and CRP. Predictive models indicated that home range and core area was smaller in landscapes where forest and grassland habitat was less fragmented. Predictive models indicated home range shape was more circular in landscapes with low forest patch density within the home range. We were unable to realistically predict home range size at the county scale, largely due to a greater amount of variation in patch size at the county scale as compared to the home range scale. The differences seen between the habitat variables for bobcat home ranges and those for the counties within our study area emphasize that a priori habitat selection at the landscape scale is likely occurring. This result has practical implications as to where bobcats may be expected to persist in other areas of Iowa and the Midwest.

Key words**:** bobcat, fragmentation, habitat selection, home range, Iowa, landscape, *Lynx rufus*

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Introduction

At the time of settlement bobcats were widespread in the prairie woodland complexes of the Midwest, but by the late-1970s they were considered rare throughout the Corn Belt region (Deems and Pursley 1978). The disappearance of bobcats from this region has been attributed primarily to an increase in the amount of land converted to agriculture and to unregulated harvest (Rolley 1987, Woolf and Hubert 1998). In 1977 the Department of Natural Resources (DNR) listed the bobcat as Endangered in Iowa. Around that same time bobcats also became protected in Illinois, Indiana, and Ohio (Woolf and Hubert 1998). Since then, periodic reports of presence of bobcats in Iowa have occurred, with a dramatic increase in these reports since the early-1990s. Based on the increased number of bobcat sightings, incidentally trapped bobcats, and automobile killed bobcats, the species status was changed to Threatened in 2001 and then changed to Protected in 2003. As bobcats return to Iowa and other areas of the Midwest, managers must be equipped with an understanding of how they are using this altered landscape to ensure their persistence.

Iowa is an agriculturally dominated landscape consisting of almost 60% annual row crops (Figure 1). The result is a fragmented mosaic of more preferred bobcat habitats such as forest (Hall and Newsom 1976, Lovallo and Anderson 1996, Nielsen 2000, Rucker et al. 1989) and grassland (Kamler and Gipson 2000). This fragmentation of forest and grassland habitats into patches may affect bobcats by limiting their movements, altering home range boundaries, and modifying habitat selection patterns (Sunquist and Sunquist 2001). Large areas of forest are uncommon in Iowa compared to several other areas where habitat selection of bobcats has been examined, such as Wisconsin (Lovallo and Anderson 1996) and Mississippi (Chamberlain et al. 2003).

In recent decades the enrollment of land into the Conservation Reserve Program (CRP) has led to increases in the amount of grasslands available to bobcats and their prey. Kamler and Gipson (2000) showed that bobcats selected grassland over forest in Kansas, which may suggest that CRP lands could aid bobcats in their reestablishment of Midwest landscapes. The importance of CRP lands to bobcats has not yet been studied.

Our objectives were to (1) examine the sex-specific space use of bobcats by calculating their mean utilization distributions, (2) estimate habitat selection ratios of bobcats at multiple scales, in order to determine the importance of forest, grassland, and CRP habitats to the species, and (3) create predictive habitat models to gain insights into the effects of fragmentation on bobcat habitat use and configuration. By utilizing multiple methods of habitat analysis, we will be able to determine general selection patterns as well as the effects of specific habitat variables on bobcat area usage. It is our intent that these results will better equip managers in Iowa and other areas of the Midwest with an understanding of how bobcats are exploiting one of the most heavily farmed areas within their range. In addition, these results have practical implications for predicting the spread of bobcats throughout Iowa.

Study area

We trapped and radio-collared bobcats in 8 counties in south-central Iowa (Figure 2). We chose these counties on the basis of their proportion of forest habitat, number of reported bobcat sightings and incidentally-trapped bobcats in recent years, and for logistical reasons. The major habitat types in the study area are grasslands/pastures (41%), row crops consisting primarily of corn and soybeans (27%), forest (15%), and CRP (11%). Human population density in the study area averages 11 persons/km^2. Mean road density, including paved and unpaved roads, is 1.22 km/km^2.

Methods

Capture

We captured bobcats using baited box traps (Tomahawk Co., Model #TLT 209.5) or No. 3 Victor Softcatch® foothold traps (Woodstream Corp., Lititz, PA). Additionally, we processed and fitted with radio collars bobcats that were incidentally live-captured by licensed private trappers if they fell within or adjacent to the study area. We anesthetized the bobcats via an intramuscular injection of Ketamine HCl and Xylazine HCl (5:1, 10 mg/kg). We ear tagged each individual with an individual identification number. We estimated age based on weight and tooth condition to determine which collar type to use. Age estimates consisted of three categories: (1) kitten, milk teeth present and weighing <3.5 kg, (2) juvenile, no tooth wear visible and individual weighing between 3.5-5.5 kg, and (3) adult, some tooth wear present and weighing ≥ 5.5 kg.

We fitted juvenile bobcats with standard VHF radio collars (Advanced Telemetry Systems, Isanti, MN, USA) equipped with a foam insert to allow for future growth. We fitted adult bobcats with either a standard VHF radio collar (Advanced Telemetry Systems, Isanti, MN, USA; Lotek Wireless, Newmarket, Ontario, Canada) or a GPS collar (Lotek Wireless, Newmarket, Ontario, Canada). In all cases, we ensured that the radio collar weighed ≤5% of the individual's body weight. All radio collars were equipped with mortality sensors. GPS radio collars were also equipped with drop-off mechanisms to allow for data recovery. Capture and handling procedures were conducted in accordance with Iowa State University Institutional Animal Care and Use Committee protocol (5-03-5447-W).

Radiotelemetry

We conducted radiotelemetry using vehicle mounted yagi antennas arrayed in a null-peak configuration (Samuel and Fuller 1996). We used Location Of A Signal (LOAS) 3.0.4 software (Ecological Software Solutions^{TM}, Sacramento, CA, USA) and a global positioning system (GPS V^{TM}, Garmin Ltd., Olathe, KA, USA) to triangulate bobcat locations. We determined the locations using ≥2 bearings taken in ≤15 minutes of one another. We used the maximum likelihood algorithm in LOAS to calculate telemetry error for bobcat locations. This produced error ellipses from triangulation based on the multiple azimuths (Millspaugh and Marzluff 2001). We used test collars at known locations to determine the accuracy (i.e. standard deviation) and precision (i.e. bias) of our radiotelemetry methods (White and Garrott 1990, Millspaugh and Marzluff 2001).

We located each bobcat 1-2 times per week (hereafter, point locations). In addition to point locations, we sequentially tracked a sample of adult females 16 weeks each year during the months of April-September. We tracked these females for a 6-hour sampling period once a week. During the sampling period, we located each female every 15-30 minutes (hereafter, sequential locations). We rotated tracking schedules every week so that the point and sequential locations were collected throughout the entire diel period, which takes into account habitats used for both resting and foraging and other active behaviors. At the time of location, we recorded the bobcat as either active or resting depending on the variability in the radio signal. We located GPS-collared bobcats on the same schedule as VHF-collared bobcats. Upon recovery of a GPS collar, we downloaded the stored data and combined it with the triangulated locations. Bobcats missing for ≥10 days were located from a fixed-wing aircraft.

Space Use

We used SAS 9.1 software (SAS Institute Inc., Cary, NC, USA) to create a data set for each bobcat including all point locations, one randomly selected sequential location from each sampling period, and the 3-D locations from recovered GPS collars. Only 3-D locations were used from GPS collars that were typically accurate to ≤100 m (Gosselink and Clark 2004). We removed any locations that were <24 hours apart to increase the independence between locations (White and Garrott 1990). We examined the statistical distribution of location error ellipses and removed locations in the upper 10% (>16.36 ha, White and Garrott 1990). We examined all data sets for errors and inconsistencies such as incorrect data entry, insufficient amounts of information, and proper time succession. In addition, we split the location data into 2 seasons: (1) 1 April-30 September and (2) 1 October-31 March, based on changes in female space use and activity during the denning and kitten-rearing times of year.

We calculated home ranges and cores of adult resident bobcats using a Fixed-Kernel estimator with least squares cross validation (Worton 1989, Seaman and Powell 1996) in the Animal Movement extension (Hooge and Eichenlaub 1997) for ArcView (Environmental Systems Research Institute, Redlands, CA, USA). This method can produce multiple polygons for each utilization distribution (UD). We used a 95% UD to calculate home range areas and a 50% UD to calculate core areas (Powell 2000). We determined the number of locations necessary for estimating UDs by randomly selecting locations from each bobcat data set at intervals of 5, and then calculated a home range from those randomly selected locations (Seaman et al. 1999). We used analysis of variance procedures to examine the change in home range size as a function of the number of locations used to calculate the home range. We considered a bobcat a resident if it had not made a permanent one-way movement outside the boundary of the natal or previously established home range. We transformed all UDs logarithmically to approximate a normal distribution. We used a mixed model procedure (SAS Institute Inc., Cary, NC, USA), which accounts for multiple observations on the same individual, to test for differences in home range and core size between sexes, seasons, and years.

Habitat Selection

We examined habitat selection at several different scales (Johnson 1980) using three different methods, similar to the approach taken by Chamberlain et al. (2003). First, we compared the habitat composition of home ranges to that of the study area. We modified the original 8-county study area to include additional areas where bobcats were radio tracked, and then removed areas north of the Middle and Des Moines Rivers, which may have been barriers to bobcat movements (Figure 3). Secondly, we compared the habitat composition of cores to that of home ranges. Thirdly, we compared the habitat composition of the point locations where bobcats were found compared to their home ranges. To accomplish this latter analysis, we buffered each point location with an area equivalent to the median error ellipse for all locations (3.75 ha, Gosselink et al. 2003), and calculated the habitat composition within these buffers.

We used the Iowa Department of Natural Resources, Geological Survey 2002 Land Cover raster data set, which was created using Landsat satellite imagery with a spatial resolution of 15 m. We collapsed the original 17 land covers into 9 habitat classes that we determined would be functionally important for bobcats (Table 1): (1) Water/Wetland, (2) Forest, (3) Grassland, (4) CRP, (5) Row crop, (6) Road, (7) Residential/Industrial, (8) Barren, and (9) Unclassified.

We used compositional analysis (Aitchison 1982, Aebischer et al. 1993) to determine sex specific habitat selection. Compositional analysis regards the animal as the sampling unit, which lessens statistical dependence on the number of locations available, accounts for the non-independence of locations, and allows for the separation of data into subgroups such as sex and age (Aebischer and Robertson 1992). In addition, compositional analysis adheres to the unit sum constraint (Aebischer et al. 1993) which recognizes that selection for one habitat will result in the apparent avoidance of other habitats. We removed the Unclassified habitat class from the analysis because it was not present in any of the home ranges. We used Barren as the reference habitat class. We used multivariate analysis of variance (MANOVA) procedures (SAS Institute Inc., Cary, NC, USA) to test for differences between the log-ratios of used and available habitats. If the MANOVA results indicated significant selection, we used *t*-tests ($\alpha = 0.05$) to determine if there was a difference between pairs of habitat classes and to create rank matrices. For both the MANOVA and *t*-tests, we weighted the log-ratios by the square root of the number of locations for each animal (Phillips et al. 2003). We also calculated standardized selection ratios using the geometric mean (Pendleton et al. 1998) for each habitat class to determine the magnitude of selection (Phillips et al. 2003). We demonstrated the relative strength of selection among habitat classes using the inverse of the number of resources available (0.125; Krebs 1999).

Habitat Model

Home range and core size. We used multiple linear regression to predict home range and core size as a function of composition, class, and landscape habitat variables (Manly et al. 2002). We calculated the composition variables from GIS layers created by the Iowa DNR, Geological Survey which included variables such as stream and road density. We used FRAGSTATS 3.3 (McGarigal and Marks 1995) to calculate class and landscape variables. Class variables are measurements pertaining to a specific habitat class such as forest patch density. Landscape variables are calculated across the entire landscape mosaic and include measurements such as patch density, regardless of habitat class. From these sources, we chose 38 home range and 38 core habitat variables that we felt were biologically important to bobcats. We checked these variables for normality and transformed non-normal variables logarithmically. We designated composition variables with a large proportion of missing values as either present or absent. We reduced the number of potential predictor variables by removing one variable from each pair of correlated variables based on a Pearson's correlation coefficient of ≥ 0.70. We further reduced the variable set using univariate tests and by examination of scatter plots (SAS Institute Inc., Cary, NC, USA). We tested variables suspected of having a non-linear relationship with home range or core size to determine their proper expression. These preliminary analyses reduced potential predictor variables to 12 home range (Table 2) and 12 core habitat variables (Table 3).

We used R-square model selection (SAS Institute Inc., Cary, NC, USA) to calculate the 3 best-fit home range and core size models for each number of variables possible. We forced sex into all models as a main effect because of the significant difference in size between UDs for females and males (Anderson 1987, Larivière and Walton 1997). We considered only linear models without interactions for simplicity. We then compared the best-fit 3-, 4-, 5-, and 6-variable candidate models using Akaike's Information Criterion, corrected for small sample size (AIC_C; Burnham and Anderson 2002). We ranked candidate models using ΔAIC_C values, and assessed the relative likelihood of each model using Akaike weights (w_i; Burnham and Anderson 2002). We also used R-square model selection to calculate the best-fit models where sex and the number of UD polygons were forced into each model as main effects. We again compared the best-fit 3-, 4-, 5-, and 6-variable candidate models using AIC_C. Finally, we compared the 2 best-fit candidate models where sex was a main effect with the 2 best-fit candidate models where sex and the number of UD polygons were main effects using AIC_C. We were unable to incorporate age into the models because we were missing exact age information for 32% of our adult individuals.

Home range shape. In addition to creating predictor models of size, we used the habitat variables to create predictive functions of home range shape. We calculated a shape index defined as

$$S = p / (2\sqrt{A*\pi})$$

where p is the perimeter of the home range and A is the home range area (Forman and Godron 1986). This measurement is an index of how much more home range perimeter there is compared to a circle with the same area. A minimum shape index of 1.00 indicates a circular home range.

We used the same procedures as described above to reduce the original set of 38 predictor habitat variables to 12 (Table 4). We forced the number of home range polygons into all models to account for its effect on the shape index because it is directly related to the amount of perimeter. We also calculated a set of models with sex and the number of home range polygons included as main effects. Similar to the procedures described above, we first compared models that incorporated the number of home range polygons as a main effect separately from those that incorporated sex and the number of home range polygons as main effects. We then compared the 2 best-fit candidate models where the number of home range polygons was a main effect, with the 2 best-fit candidate models where sex and the number of home range polygons were main effects.

We tested the utility of our modeling exercises at the county scale by calculating the same composition, class, and landscape variables for each county within the original 8-county study area. We then used the best-fit regression model and the county level habitat variables to predict the mean home range size. We were interested in predicting home range size at the county level to gain insights about the occurrence and density of bobcats at a practical management scale.

Results

Capture and Radiotelemetry

We radio collared 44 (19 F, 25 M) bobcats from 3 March 2003 to 6 February 2005. We triangulated a total of 10,023 locations and recovered an additional 1,399 3-D locations from 7 GPS collars. Of the triangulated locations, 3,775 were point locations and 6,248 were sequential locations. We triangulated 42% of the locations from 08:00-20:00 (daytime) and 58% from 20:00-08:00 (nighttime). The proportion of active locations exceeded that of resting locations during the hours of 07:00-08:00 and 17:00-23:00 indicating a crepuscular activity pattern. Our radiotelemetry method tests using reference collars revealed a standard deviation of 5.20 and a bias of 1.19 degrees (W. R. Clark, unpublished data). We experienced 8 radio collar failures (2 F, 6 M), all of which were GPS collars. Two of the failed GPS collars (1 F, 1 M) were recovered at later dates and the location data stored on them was used for the analyses.

Space Use

We used 2,607 locations to calculate 71 home ranges and cores of 32 resident bobcats (16 F, 16 M) with an average of 39 locations (range 20-67) per UD. We determined that a minimum of 25 and 20 locations per season was sufficient for calculating UDs for females and males, respectively, from the analysis of our own data. There was no difference in home range size between years ($F_{2,14} = 0.95$, $P = 0.4115$). Home range size of males (56.74 ± 7.06 km^2; $\bar{x}$ ± SE) was consistently larger than that of females (20.16 ± 2.18 km^2; $F_{1,16} = 34.50$, $P < 0.001$; Table 5). The difference in home range size between seasons of both females and males neared significance ($F_{1,52} = 3.54$, $P = 0.07$), with females having significantly smaller home ranges in April-September (15.64 ± 2.26 km^2) as compared to October-March (26.30 ± 4.03 km^2; $t_{16} = -2.28$, $P = 0.04$).

Similarly, there was no difference in core size between years ($F_{2,14} = 0.71$, P = 0.51). Core size differed between sexes ($F_{1,16} = 52.16$, $P < 0.001$), with males (8.75 ± 1.19 km^2) maintaining larger core areas than females (2.26 ± 0.25 km^2; Table 5). The core size of females also differed significantly between seasons ($t_{16} = -2.63$, $P = 0.02$), with females having smaller cores in April-September (1.66 ± 0.25 km^2) as compared to October-March (3.09 ± 0.49 km^2).

Habitat Selection

We determined the differences in log-ratios of used versus available habitat for all bobcats were significant at all scales (Wilk's $\Lambda < 0.001$; Table 6), as were the differences for females and males separately. Forest ranked as the most important habitat class for females and males at all scales (Table 7). Grassland ranked as the second most important habitat class for females at all scales, but only at the home range versus study area scale for males.

In all cases, Grassland was ranked higher than CRP, except when comparing male core use to home range availability (Table 7).

Standardized selection ratios revealed that females and males selected Forest at a significantly higher magnitude than all other habitat classes at all scales (Figures 4-9). In most cases, the selection of Grassland did not appear to differ from random, except perhaps when comparing male core use to home range availability. Where we detected a significant difference in selection between Grassland and CRP habitat classes, Grassland always had the higher selection ratio. The selection ratio for the Row crop habitat class was less than random in all cases.

Habitat Modeling

Home range and core size. The best-fit home range size model ($R^2 = 0.80$) included 4 habitat variables (Table 8). The parameter estimates indicate that as stream density and the percentage of the home range comprised of a single row crop patch increased, home range size decreased. And, as the variability in size among all patches and row crop patches decreased, home range size decreased. When we incorporated the number of home range polygons into the models it did not improve the model fit (Table 9). We illustrate examples of small and large female and male home ranges in Figures 10-13.

The best-fit core size model ($R^2 = 0.83$) included 4 habitat variables (Table 10). The parameter estimates indicate that as the variability in size among all patches and grassland patches decreased, core size decreased. When paved roads were absent, core size decreased. And, as the habitat used comprised more of a single patch increased, core size increased. Grassland (49%) and Forest (41%) habitat classes comprised the largest single patch in most cores. When we incorporated the number of core polygons it did not improve the model fit

(Table 11). We illustrate examples of small and large female and male cores in Figures 10-13.

Home range shape. Home range shape indexes ranged from 1.30-3.37. In addition to variables that were forced into the model (i.e. number of home range polygons and/or sex), the best-fit home range shape model ($R^2 = 0.58$) included a single habitat variable (Table 12). As forest patch density decreased, the home range shape index decreased. When we incorporated sex into the models, model fit improved (Table 13). We illustrate examples of home ranges with low and high shape indexes for female and male bobcats in Figures 14-17.

When we used our best-fit regression model to predict home range size at the county scale it returned unrealistically high estimates ranging from 550-129,451 km^2 and 561-132,066 km^2 for females and males, respectively. The landscape variables calculated for each county (Table 14) were not within the range of those calculated for bobcat home ranges (Tables 2-4), particularly the variability in patch size.

Discussion

Our data indicate that female and male bobcats are using similar amounts of area as those reported in Arkansas (Rucker et al. 1989), Wisconsin (Lovallo and Anderson 1996), Missouri (Hamilton 1982), and Idaho (Bailey 1974). The nearby states of Oklahoma (Rolley 1979), Kansas (Kamler and Gipson 2000), and Illinois (Nielsen and Woolf 2001) have reported slightly smaller home ranges of both females and males. The larger home ranges seen in Iowa as compared to other Midwestern states may indicate that bobcats require slightly larger areas due to greater fragmentation and a larger proportion of annual row crop agriculture on the landscape. However, the amount of area bobcats are using in Iowa is not outside the range of those reported elsewhere. There is likely some maximum area bobcats are able to maintain despite resource availability (e.g. food and escape cover), which would explain the similarities in home range size throughout much of their range.

We found bobcats selecting Forest above all other habitat classes (Table 7). Selection for forest habitat was especially evident when point locations were compared with home ranges (Table 7, Figures 8-9). This conclusion is readily illustrated in maps of home ranges and cores (Figures 10-13). Bobcats used row crop agriculture proportionally less than its availability, which we interpret as avoidance by bobcats. These results emphasize the importance of forest habitat in predicting where bobcats will be found in Iowa and other regions of the Midwest. Similarly, Nielsen and Woolf (2002) studied bobcat spatial organization in southern Illinois and found that bobcats showed a preference for forest habitat, and abundance was negatively correlated with row crop agriculture.

Grassland was typically ranked as the second most important habitat class (Table 7) and appeared particularly important to bobcats when comparing cores to home ranges (Figures 6-7). Standardized selection ratios for Grassland and CRP were higher than random selection would predict when comparing cores to home ranges. But, when we compared point locations to the entire home range, selection for Grassland and CRP was not different from random. The difference in selection ratios between these 2 views of within home range habitat selection (Johnson 1980) indicates that although bobcats are consistently found in forests, they prefer the forest habitat within their intensive use areas (i.e. cores) to be surrounded by grasslands and CRP. In general, CRP was not consistently ranked as an important habitat class by itself. CRP never ranked higher than Forest and in most cases ranked lower than Grassland. It appears that the importance of grassland and CRP is the way in which they contribute to the context of the landscapes selected by bobcats.

Our best-fit home range and core size models indicate that in more fragmented landscapes bobcats used more area, and in less fragmented landscapes bobcats used less area. Bobcats have expressed varying degrees of territoriality (Anderson 1987, Diefenbach et al. 2006), but typically exhibit relatively little intrasexual overlap of home ranges (Kitchings and Story 1979, Lovallo and Anderson 1996) or cores (Nielsen and Woolf 2001). Therefore, as fragmentation increases and the amount of area used by bobcats increases, it is reasonable to assume that the density of bobcats will decrease. These results are consistent with those of Crooks (2002) who determined that as fragmentation increased, abundance and probability of occurrence decreased for bobcats.

The variability in patch size among all patches, as well as patches within a specific habitat class, was highly correlated with home range and core size. In all cases, as variability in patch size increased the amount of area used increased. Stream density was also an important predictor variable for home range size. The importance of this variable is likely related to the importance of forest habitat to bobcats because Iowa, like most prairie states, has much of its forested lands adjoining rivers and streams (Widner 1968). The presence or absence of paved roads was an important predictor variable for core size indicating bobcats preferred to intensely use areas with few paved roads. Other factors that may be affecting the amount of area used that we did not incorporate into our models are food availability, age, social structure, adjacencies between individuals, population density, and location on the landscape (Powell 2000).

Although the determination of home range boundaries is difficult to conclude with certainty (Powell 2000), a calculation of their approximate shape may lead to an understanding of the underlying landscape characteristics guiding their establishment. We were interested in determining which habitat variables are important to bobcats when they establish home range boundaries and may contribute to home range compaction and convolution. Our best-fit shape index regression model indicates that in landscapes with a high density of forest patches home ranges were more convoluted, and in landscapes with a low density of forest patches home ranges were more circular. This implies bobcats may be conforming home ranges to fit the arrangement and density of forest patches. This behavior would increase the costs associated with maintaining a larger home range perimeter, but could be offset by the benefits associated with forest habitat. Such benefits may include a larger prey base, escape cover from other predators and humans, and protection from the weather.

We were unable to readily utilize our best-fit regression model for home range size to predict the mean size of bobcat home ranges at the county level. Because *a priori* selection at the landscape scale is likely occurring (Johnson 1980), this result is not unexpected. Evidence for this is also seen in the representation of habitat classes within home ranges compared to within an entire county. In addition, the large difference in patch size variability between home ranges and counties suggest that this particular variable may be an important characteristic in the determination of where bobcats establish home ranges. Another possible explanation for our failure to predict home range size at the county level may be the "Modifiable Areal Unit Problem" (Openshaw and Taylor 1979, Jelinski and Wu 1996). This theory arises because of the problems associated with scaling up into larger areal units, particularly variation in results.

Management implications

Our results stress the importance of forest habitat for bobcats, especially in agricultural landscapes. While the proportion of forest habitat available may be important in determining where bobcats are found, the fragmentation and configuration of this habitat appears equally important in determining their use of space. Although it is likely bobcat will be able to continue recolonizing some areas of the Midwest, it is unlikely that they will occur in primarily agricultural areas or in densities comparable to other portions of their range.

A high level of fragmentation would not only increase the amount of direct risks to bobcats such as habitat loss, crossing roads at a higher frequency, and increased exposure to humans (Noss et al. 1996, Cain et al. 2003), but the resulting larger home ranges would also increase the energy expenditure needed to maintain that home range. The total costs of maintaining large home ranges in fragmented landscape may affect survival and in turn create population sinks in areas of low habitat suitability, such as that found throughout much of the Midwest.

Acknowledgments

The funding for this research was provided by the Iowa DNR and State Wildlife Grants. We would like to thank J. Coffey, M. Purvis, C. Duncan, N. McCann, B. Orning-Tschampl, J. Bolis, H. Stricker, C. Tucker, and M. Jones for many hours of field work. R. McNeely and J. D. Davis provided GIS assistance. In addition, this research was made possible by many trappers who assisted in capturing bobcats.

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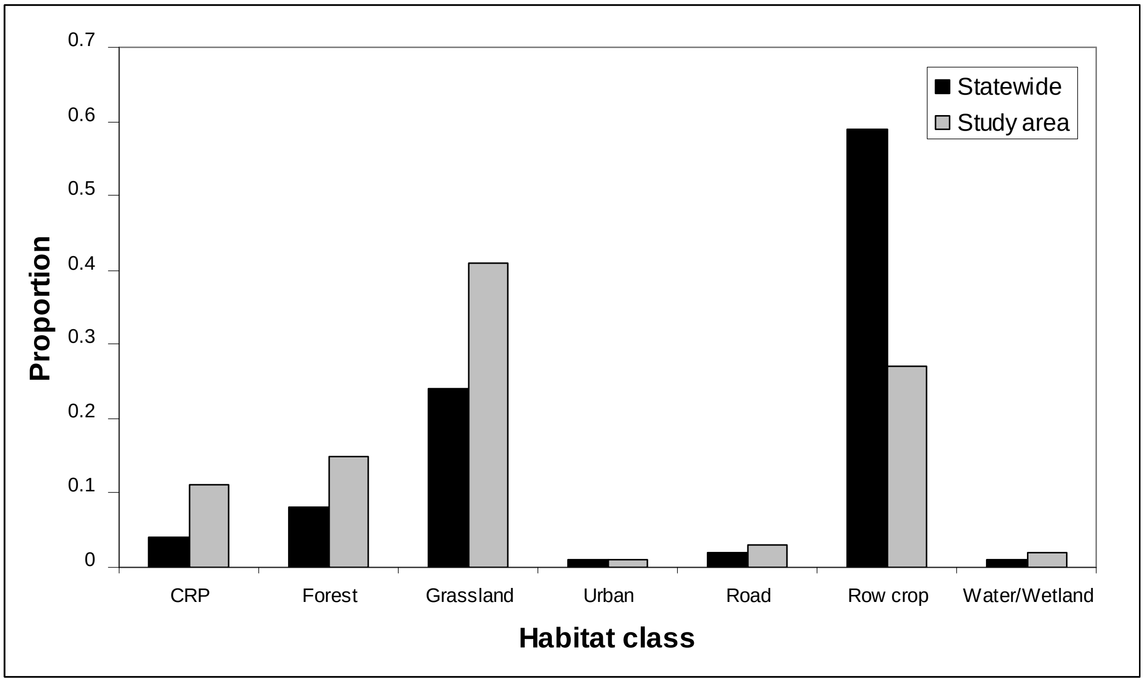

Figure 1. Proportion of each habitat class comprising the state of Iowa and the study area in south-central Iowa. The study are includes Warren, Marion, Clarke, Lucas, Monroe, Decatur, Wayne, and Appanoose counties. Land Cover was created from Landsat satellite imagery created by the Iowa DNR, Geological Survey, 2002. The original 17 land covers were collapsed into 9 major habitat classes.

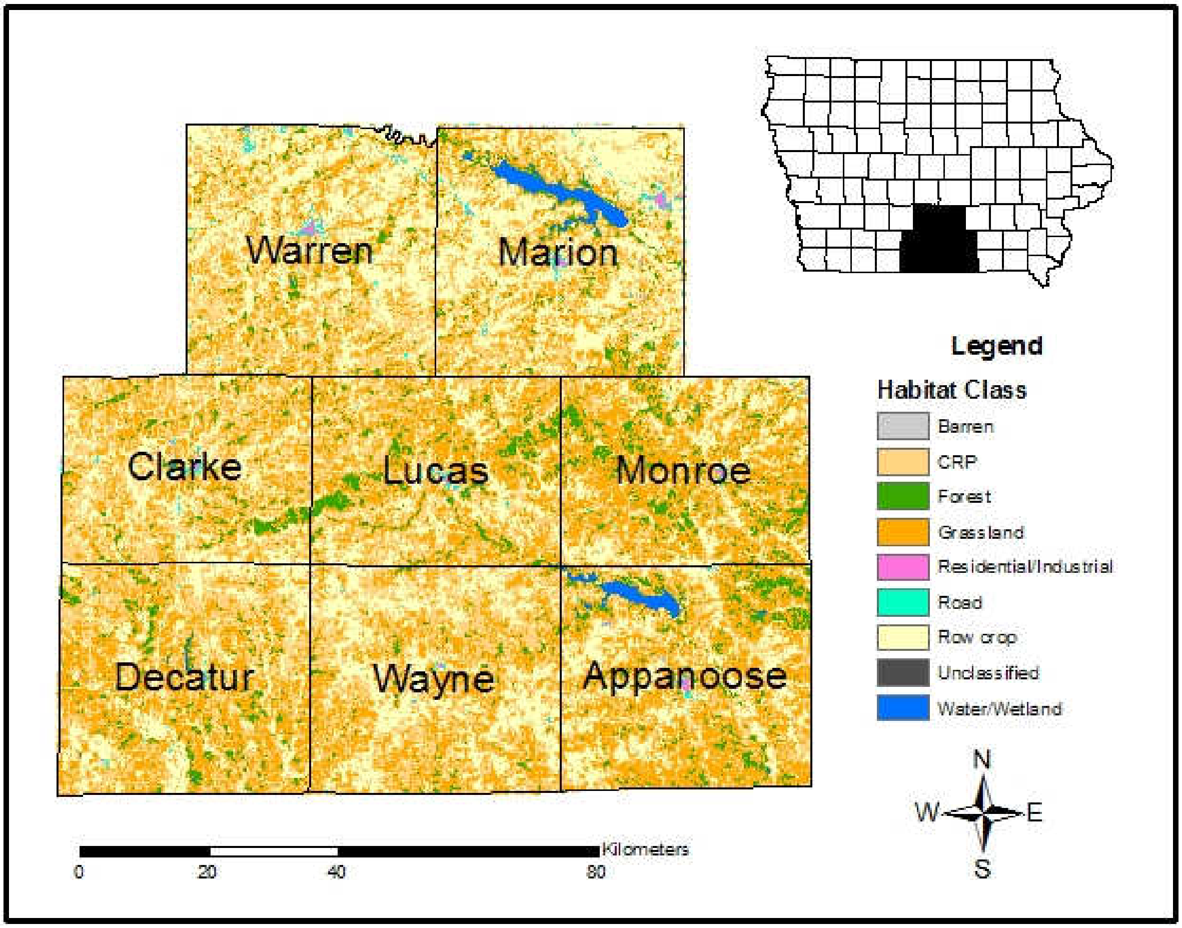

Figure 2. Study area including Warren, Marion, Clarke, Lucas, Monroe, Decatur, Wayne, and Appanoose counties in south-central Iowa. Land cover was created from Landsat satellite imagery by the Iowa DNR, Geological Survey, 2002. The original 17 land covers were collapsed into 9 major habitat classes.

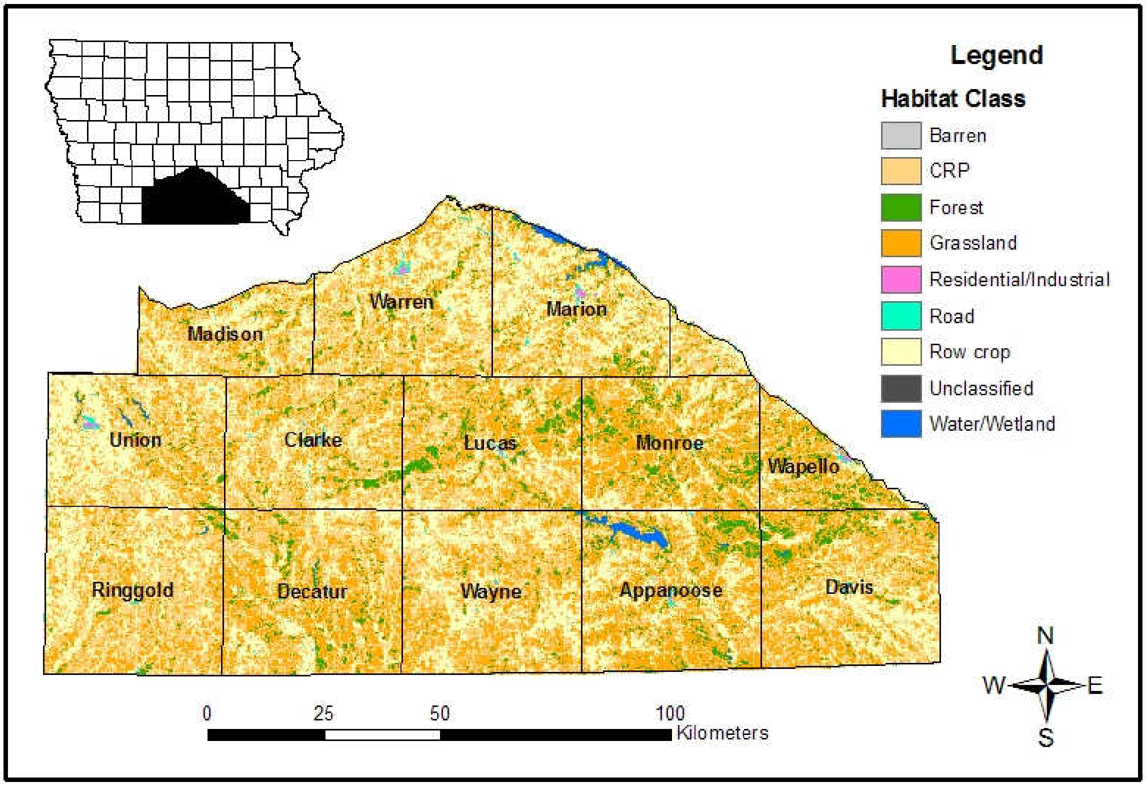

Figure 3. Modified study area used to calculate available habitat to radio-collared bobcats in south-central Iowa. Land Cover was created from Landsat satellite imagery by the Iowa DNR, Geological Survey, 2002. The original 17 land covers were collapsed into 9 major habitat classes.

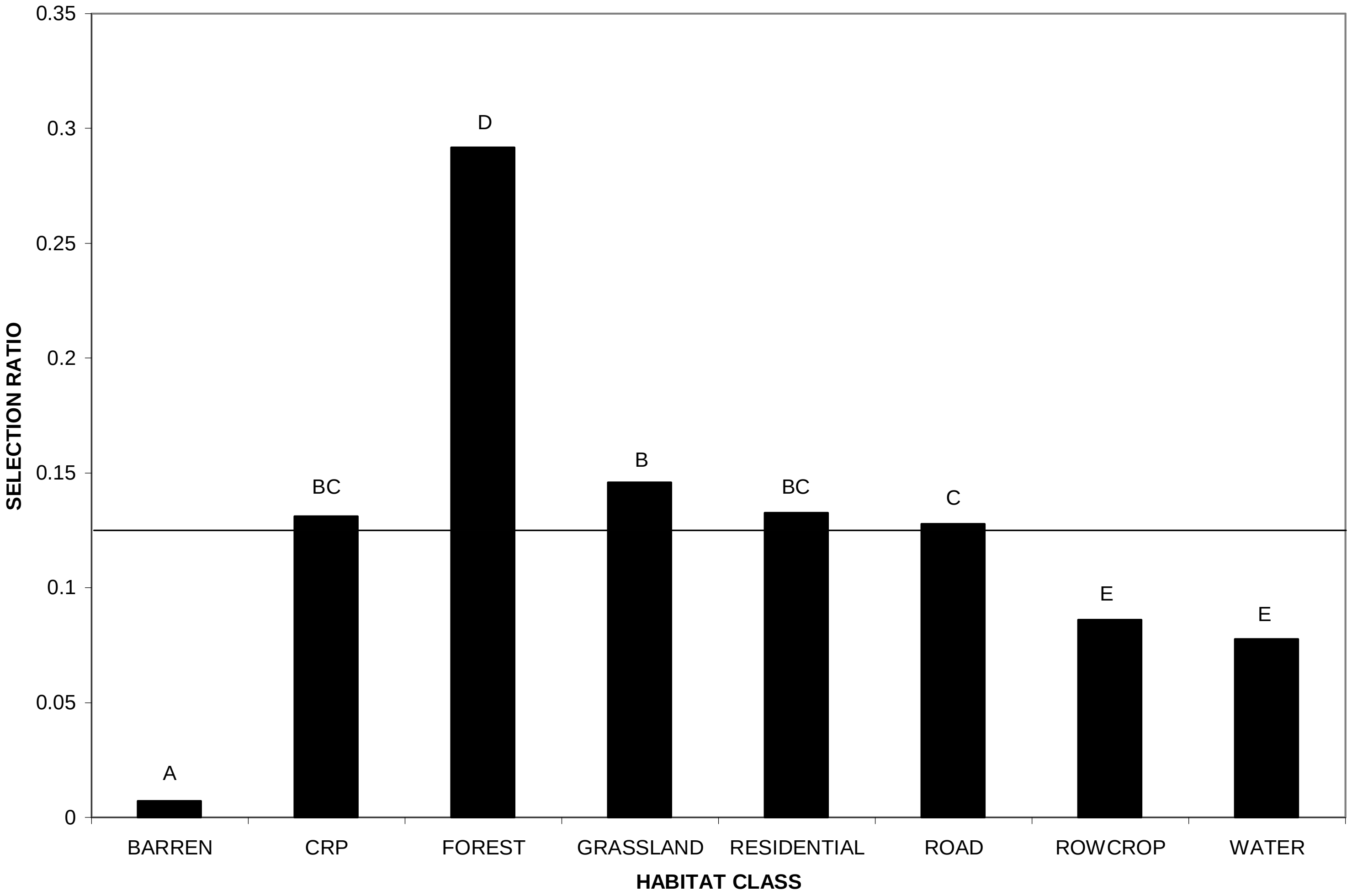

Figure 4. Standardized selection ratios of female bobcats at the home range (used) versus study area (available) scale in South-central Iowa, 2003-2005. The horizontal line indicates no selection (Krebs 1999). Habitat classes with significantly different selection ratios are indicated by different letters.

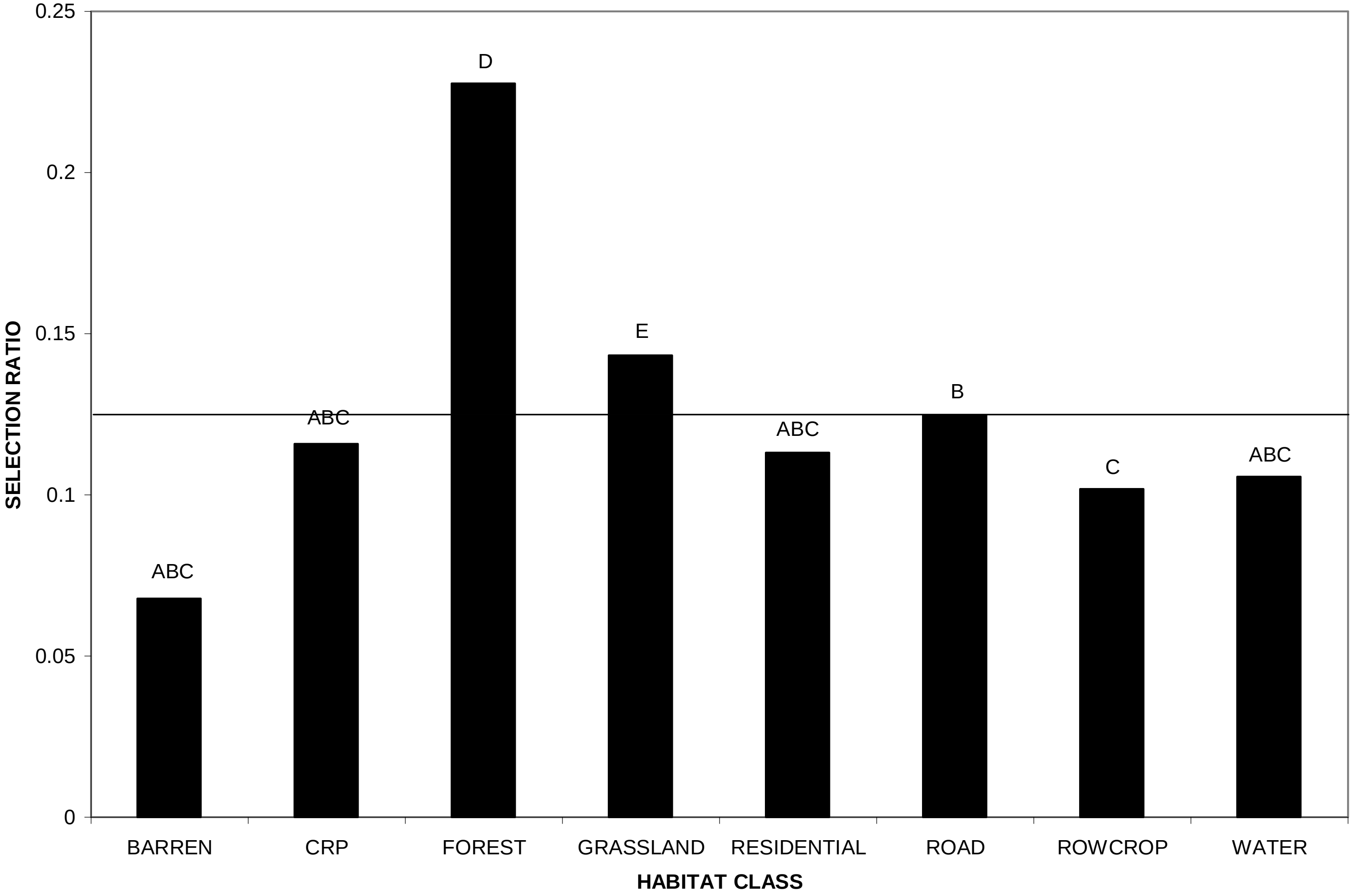

Figure 5. Standardized selection ratios of male bobcats at the home range (used) versus study area (available) scale in South-central Iowa, 2003-2005. The horizontal line indicates no selection (Krebs 1999). Habitat classes with significantly different selection ratios are indicated by different letters.

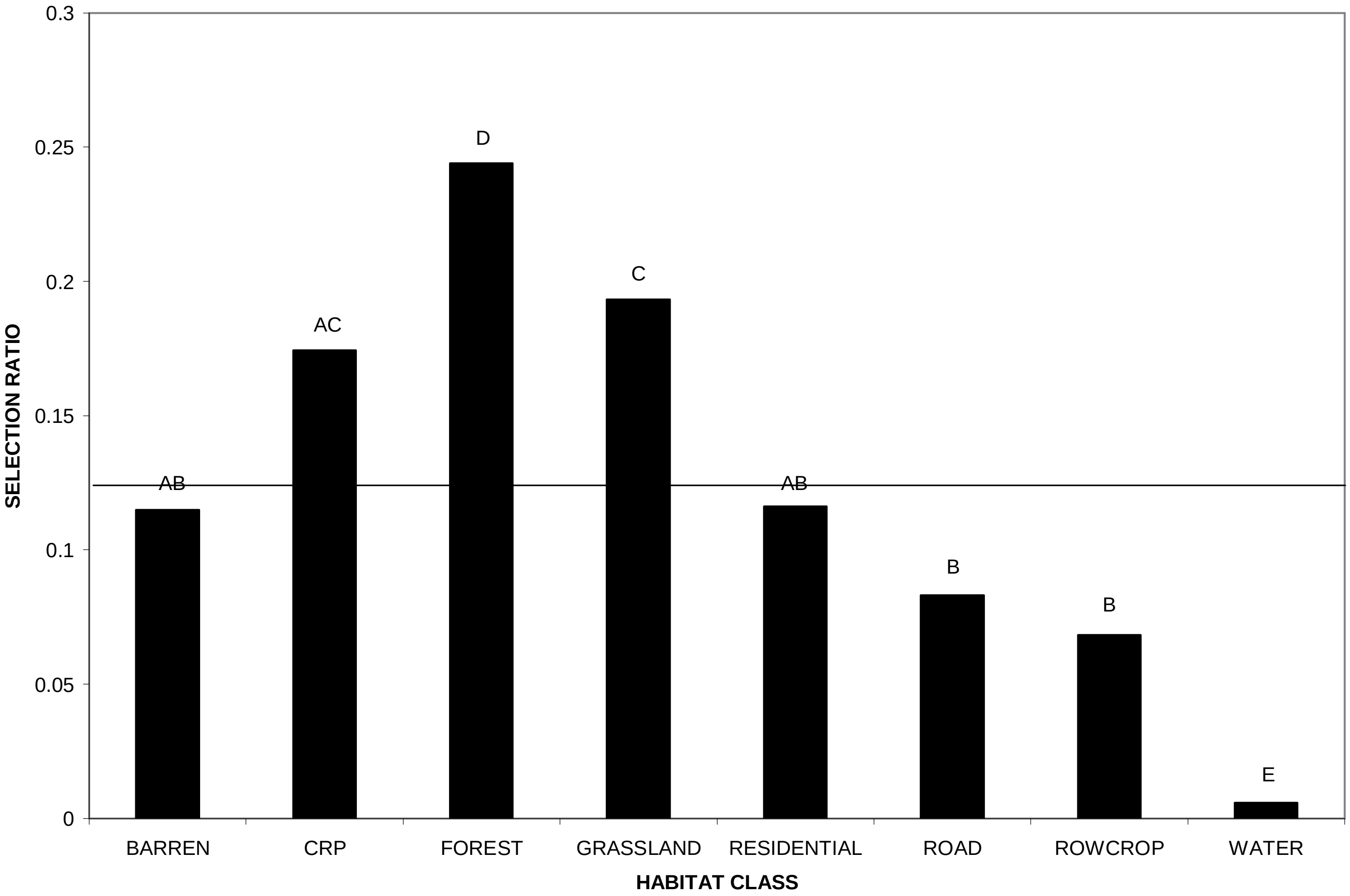

Figure 6. Standardized selection ratios of female bobcats at the core (used) versus home range (available) scale in South-central Iowa, 2003-2005. The horizontal line indicates no selection (Krebs 1999). Habitat classes with significantly different selection ratios are indicated by different letters.

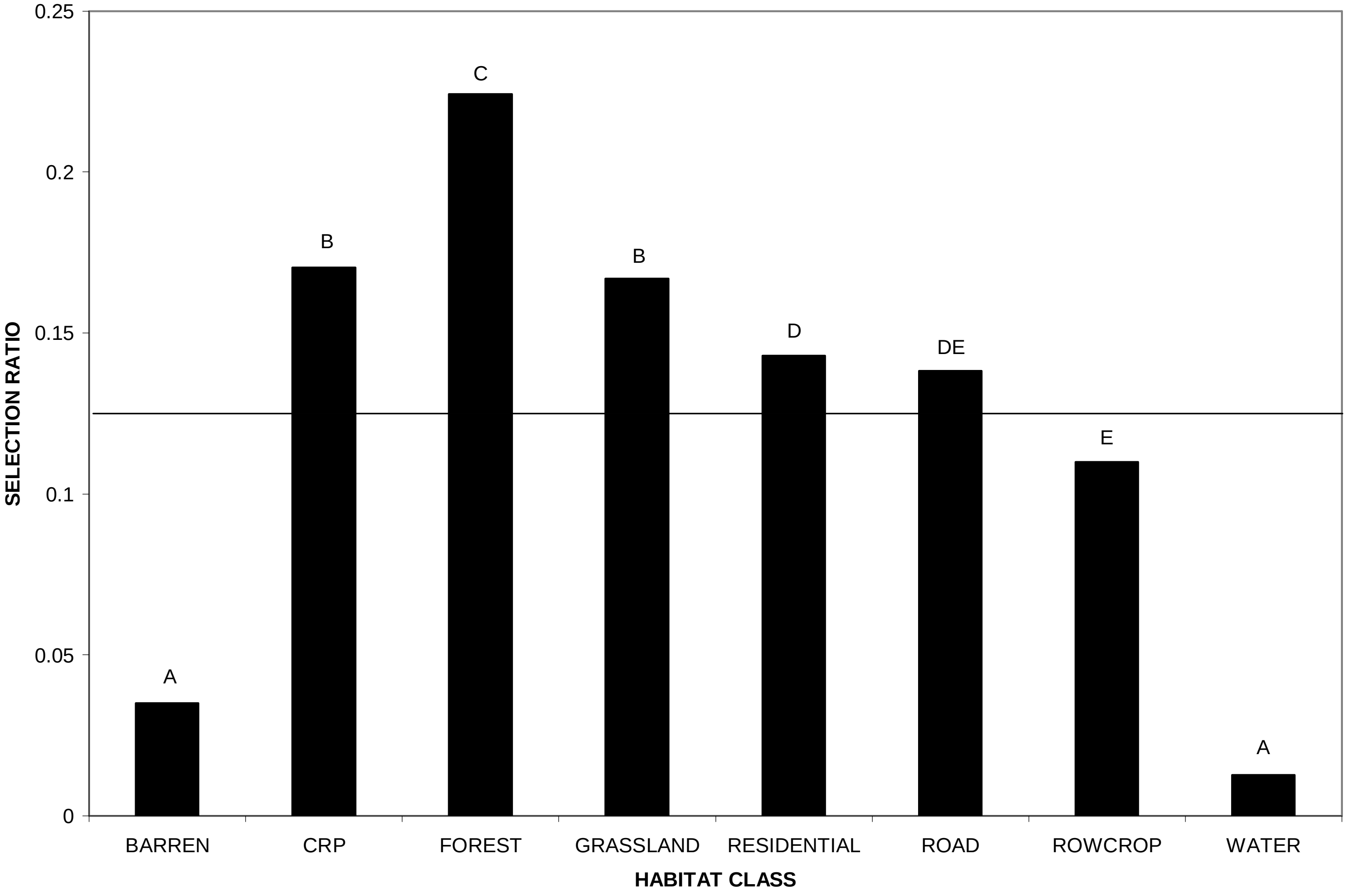

Figure 7. Standardized selection ratios of male bobcats at the core (used) versus home range (available) scale in South-central Iowa, 2003-2005. The horizontal line indicates no selection (Krebs 1999). Habitat classes with significantly different selection ratios are indicated by different letters.

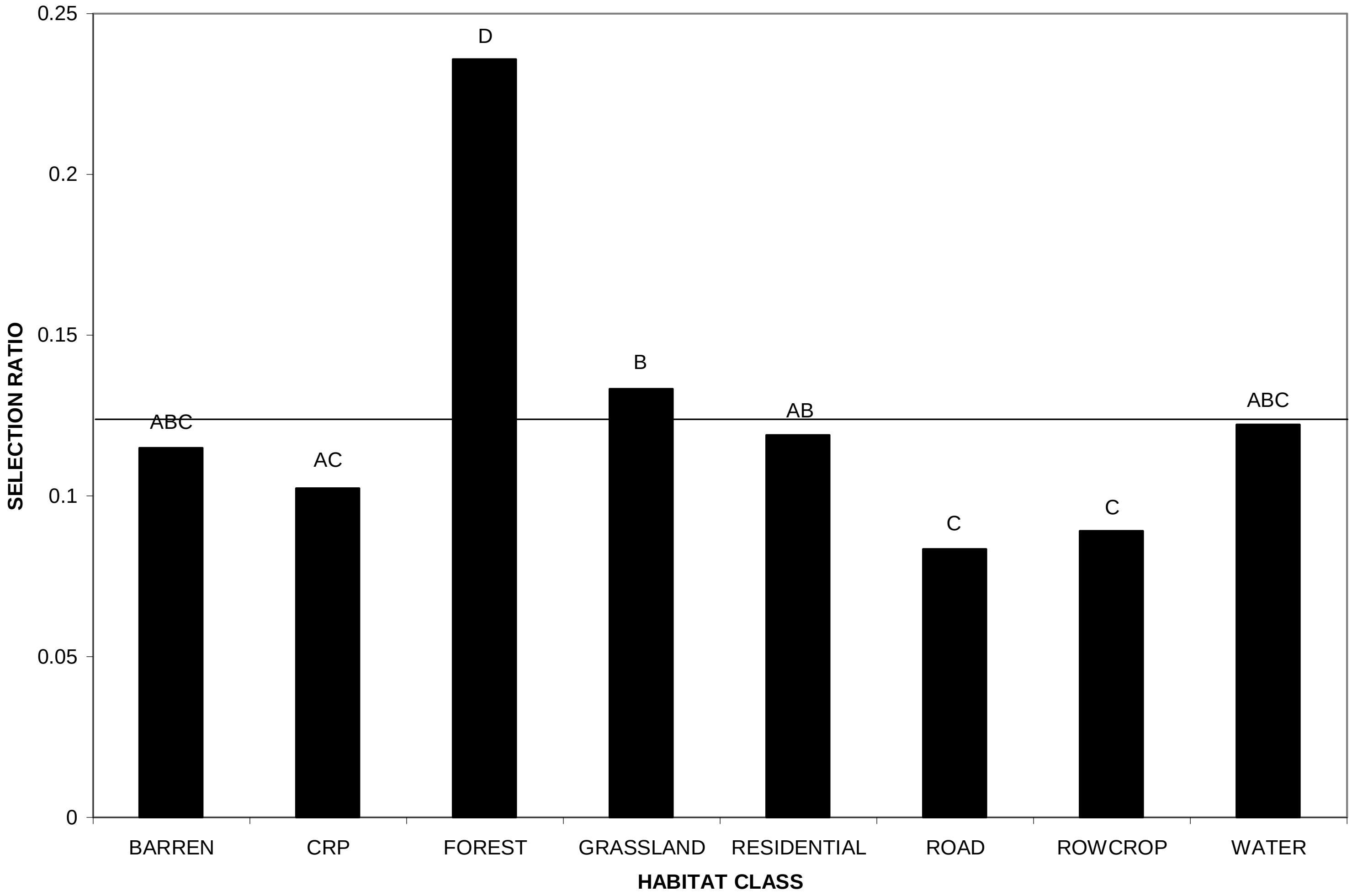

Figure 8. Standardized selection ratios of female bobcats at the point location (used) versus home range (available) scale in South-central Iowa, 2003-2005. The horizontal line indicates no selection (Krebs 1999). Habitat classes with significantly different selection ratios are indicated by different letters.

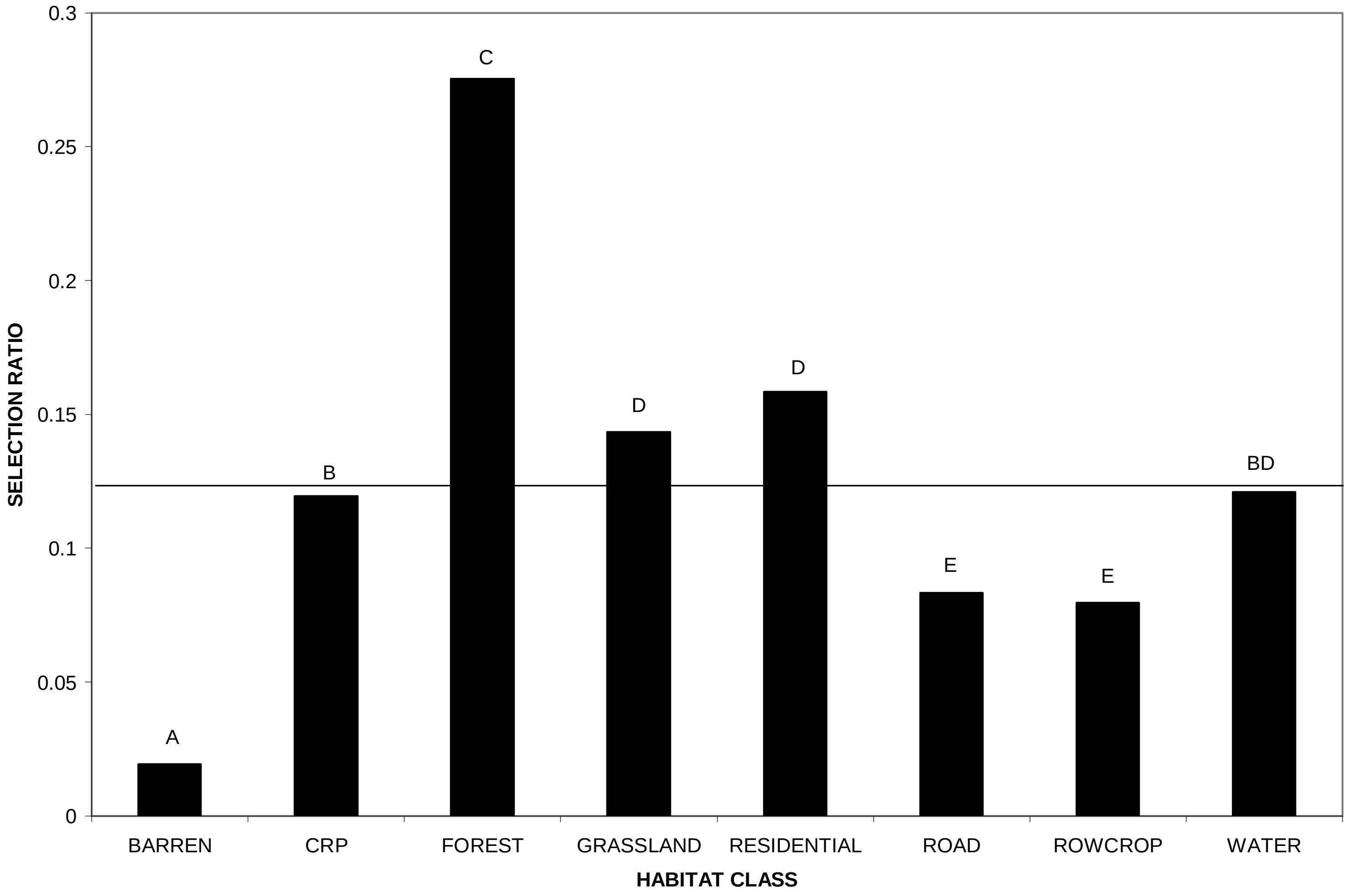

Figure 9. Standardized selection ratios of male bobcats at the point location (used) versus home range (available) scale in South-central Iowa, 2003-2005. The horizontal line indicates no selection (Krebs 1999). Habitat classes with significantly different selection ratios are indicated by different letters.

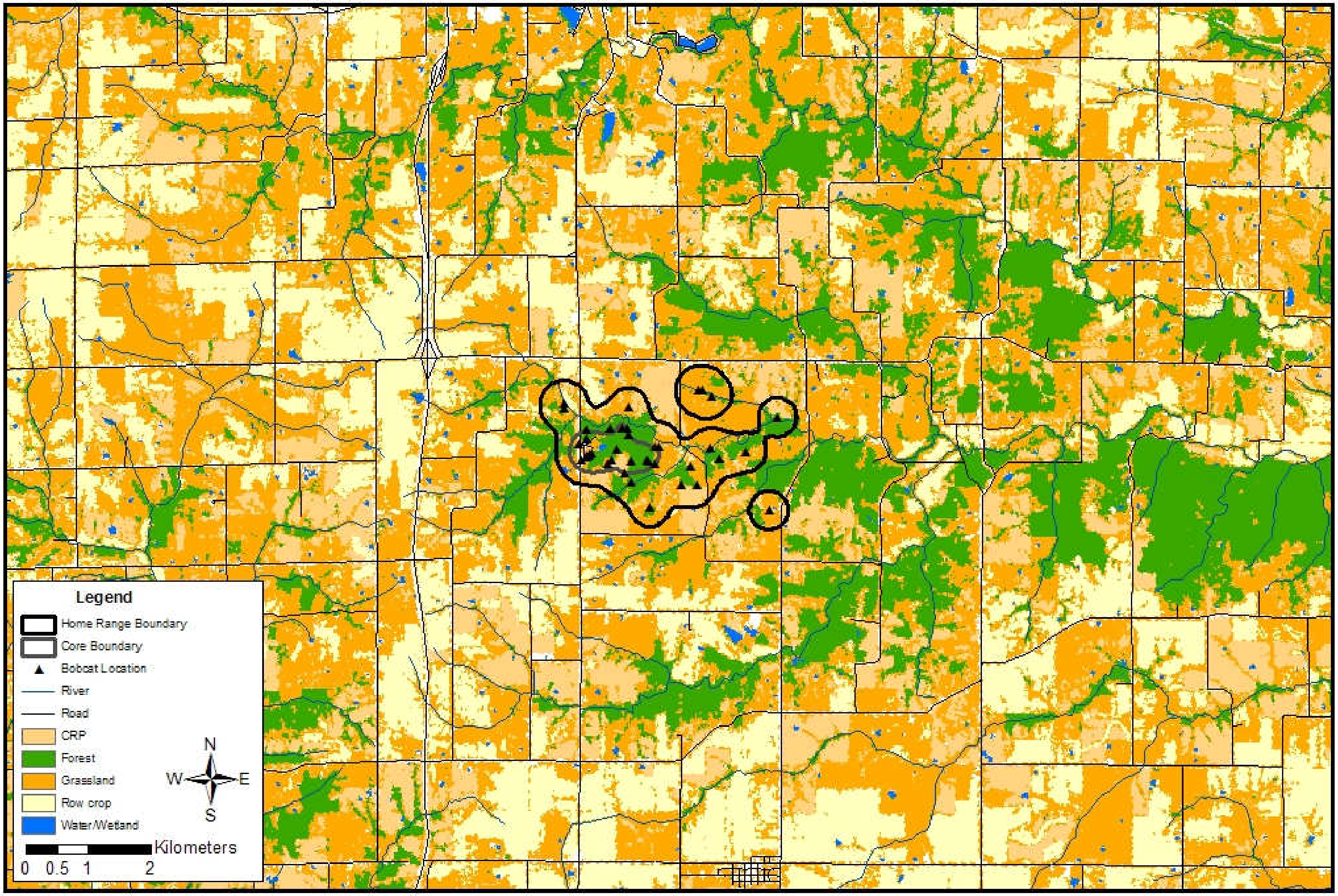

Figure 10. An example of a small home range (5.76 km^2) and core (0.77 km^2) of a female bobcat (No. 124) in Clarke County, Iowa, 2005.

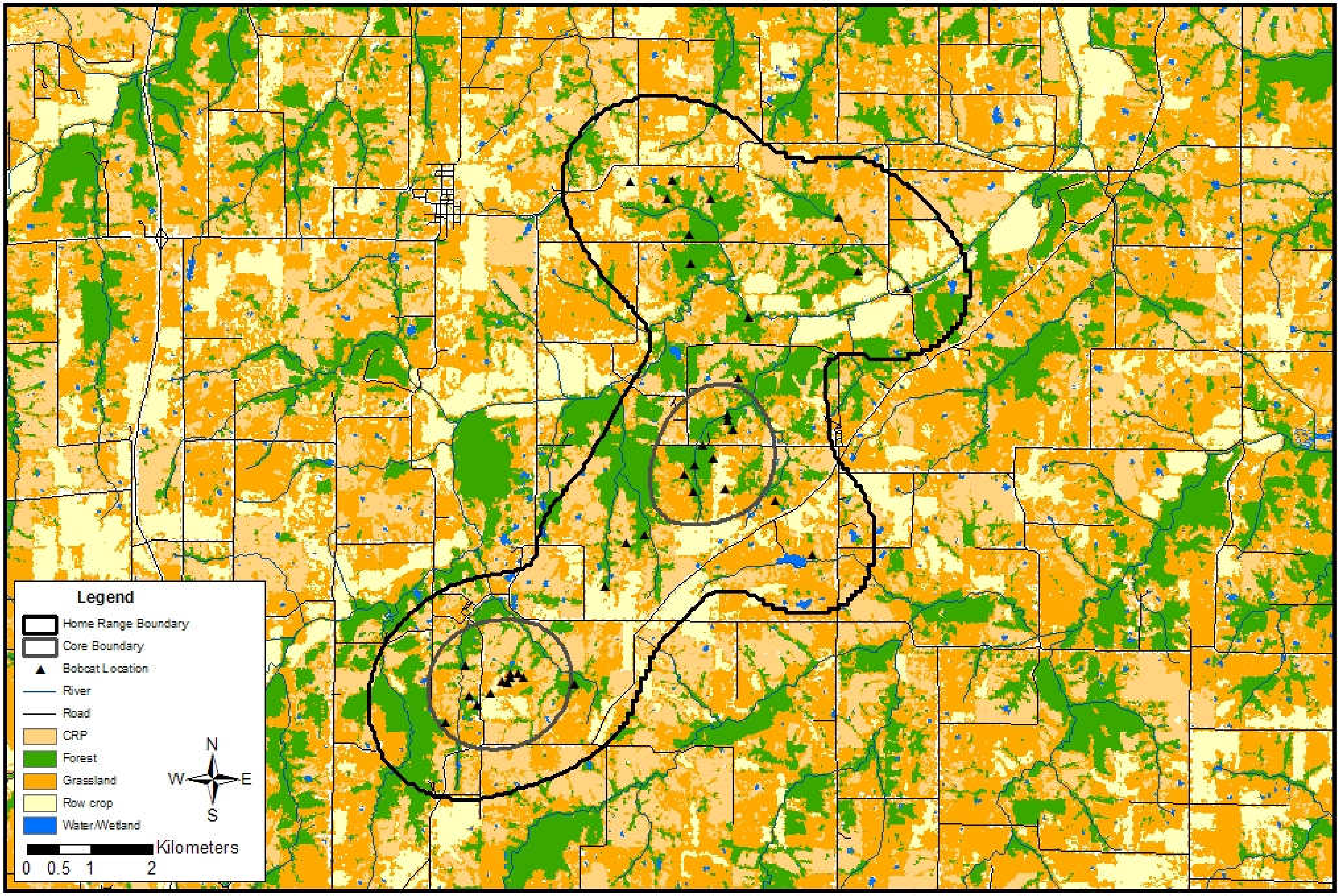

Figure 11. An example of a large home range (49.95 km^2) and core (7.34 km^2) of a female bobcat (No. 136) in Clarke County, Iowa, 2004.

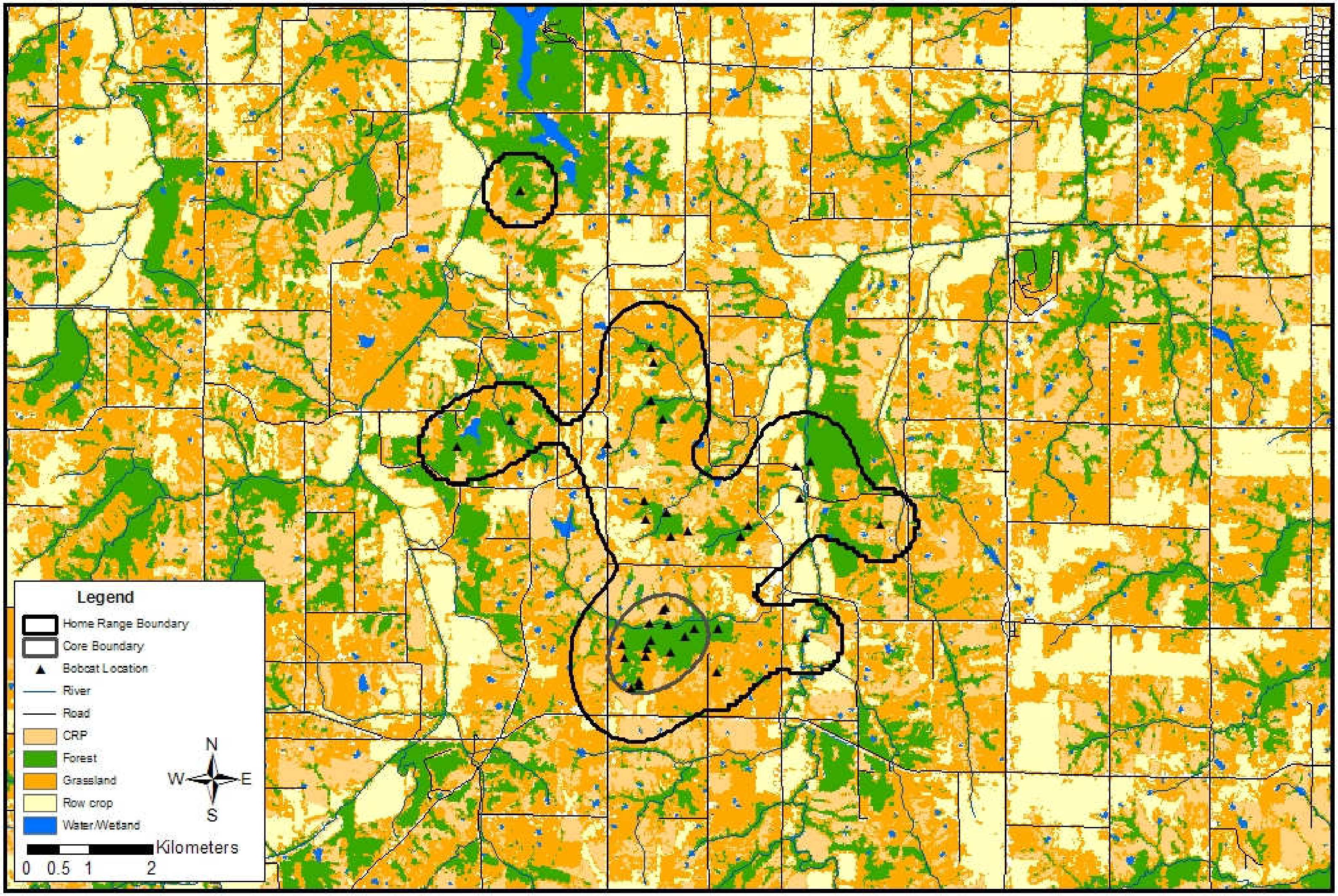

Figure 12. An example of a small home range (25.17 km^2) and core (1.92 km^2) of a male bobcat (No. 104) in Warren County, Iowa, 2004.

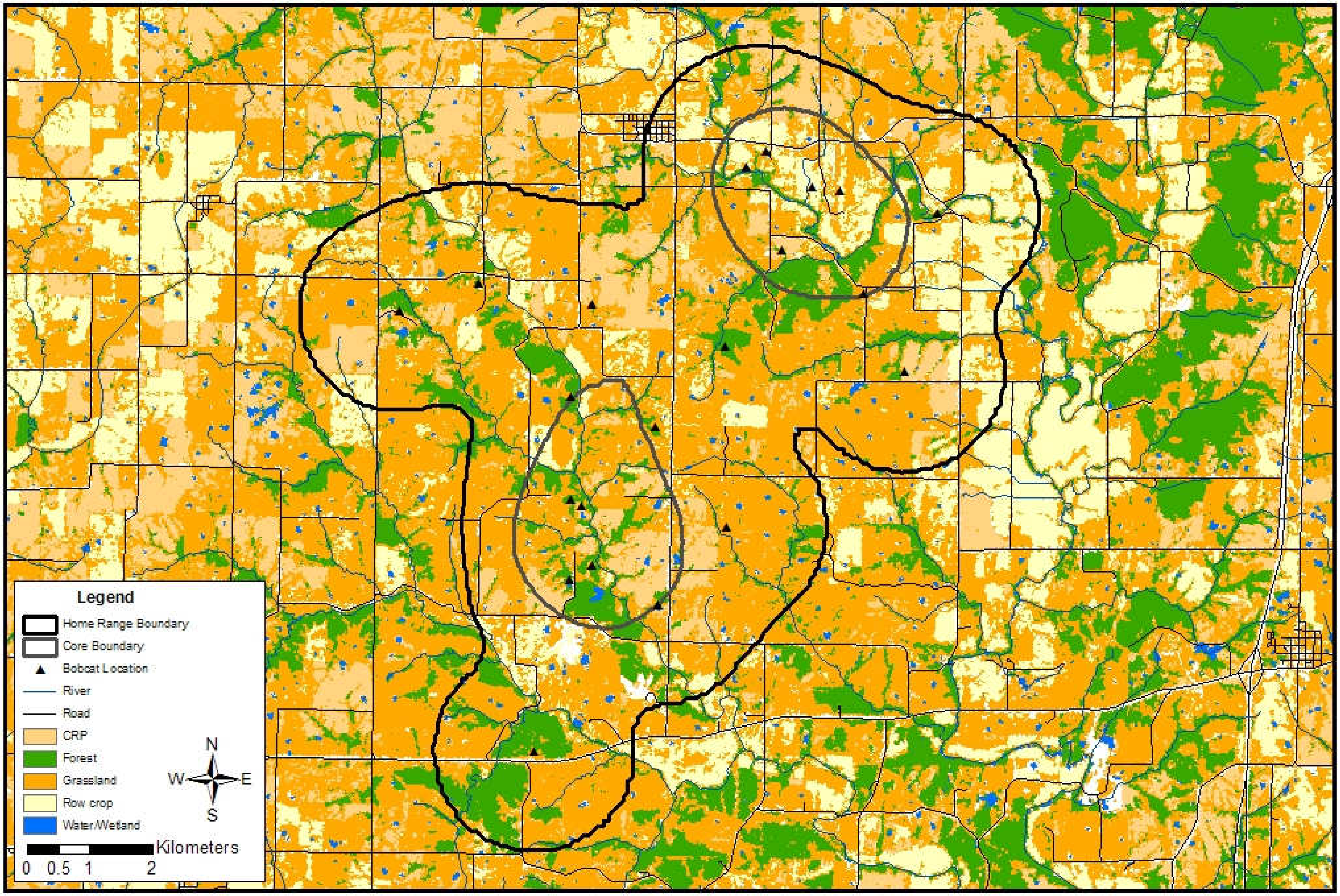

Figure 13. An example of a large home range (87.71 km^2) and core (15.95 km^2) of a male bobcat (No. 146) in Decatur County, Iowa, 2004.

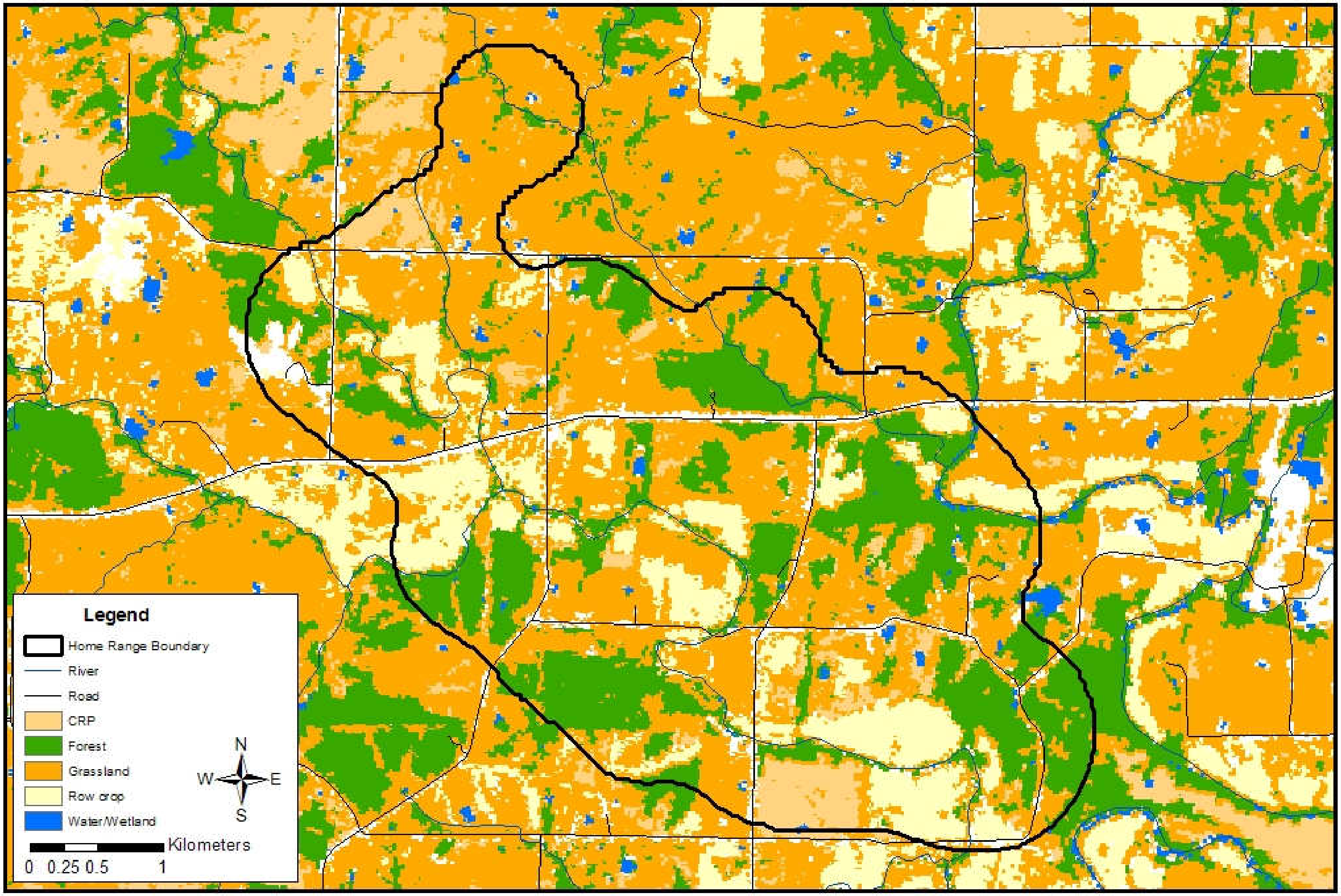

Figure 14. An example of a female bobcat home range (No. 138) with a comparatively low shape index (1.30) in Clarke County, Iowa, 2005.

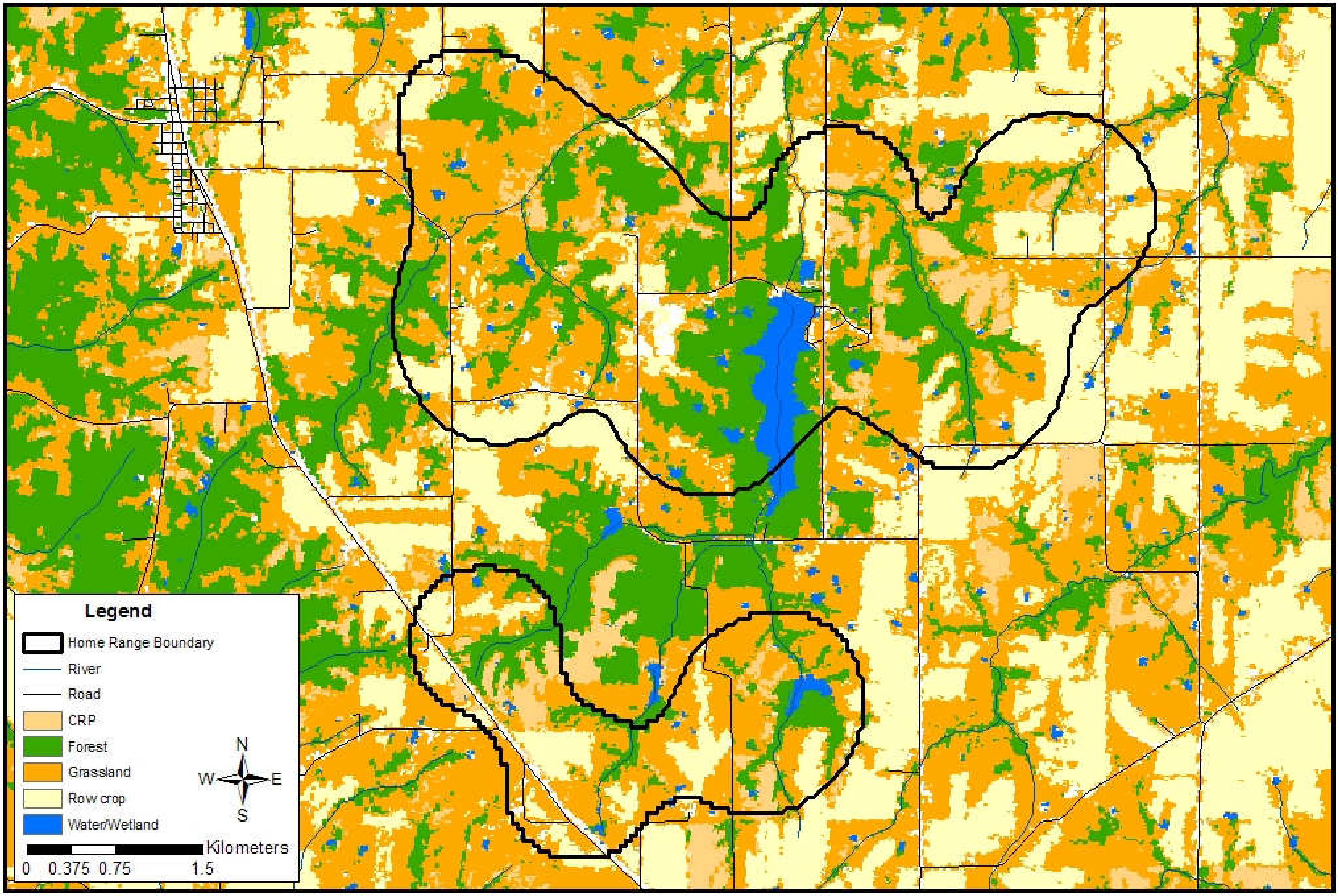

Figure 15. An example of a female bobcat home range (No. 120) with a comparatively high shape index (2.21) in Monroe County, Iowa, 2004.

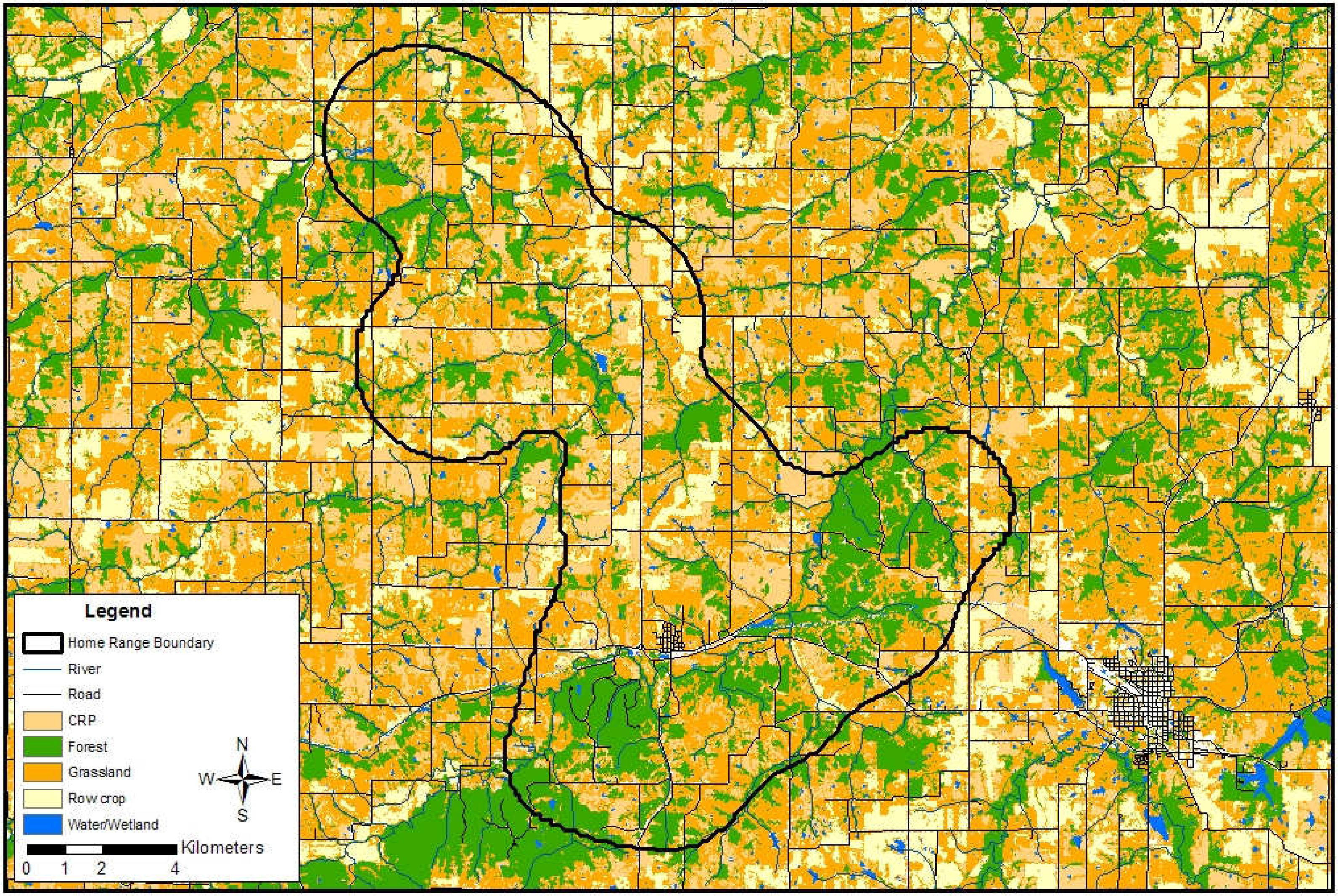

Figure 16. An example of a male bobcat home range (No. 118) with a comparatively low shape index (1.56) in Lucas County, Iowa, 2004.

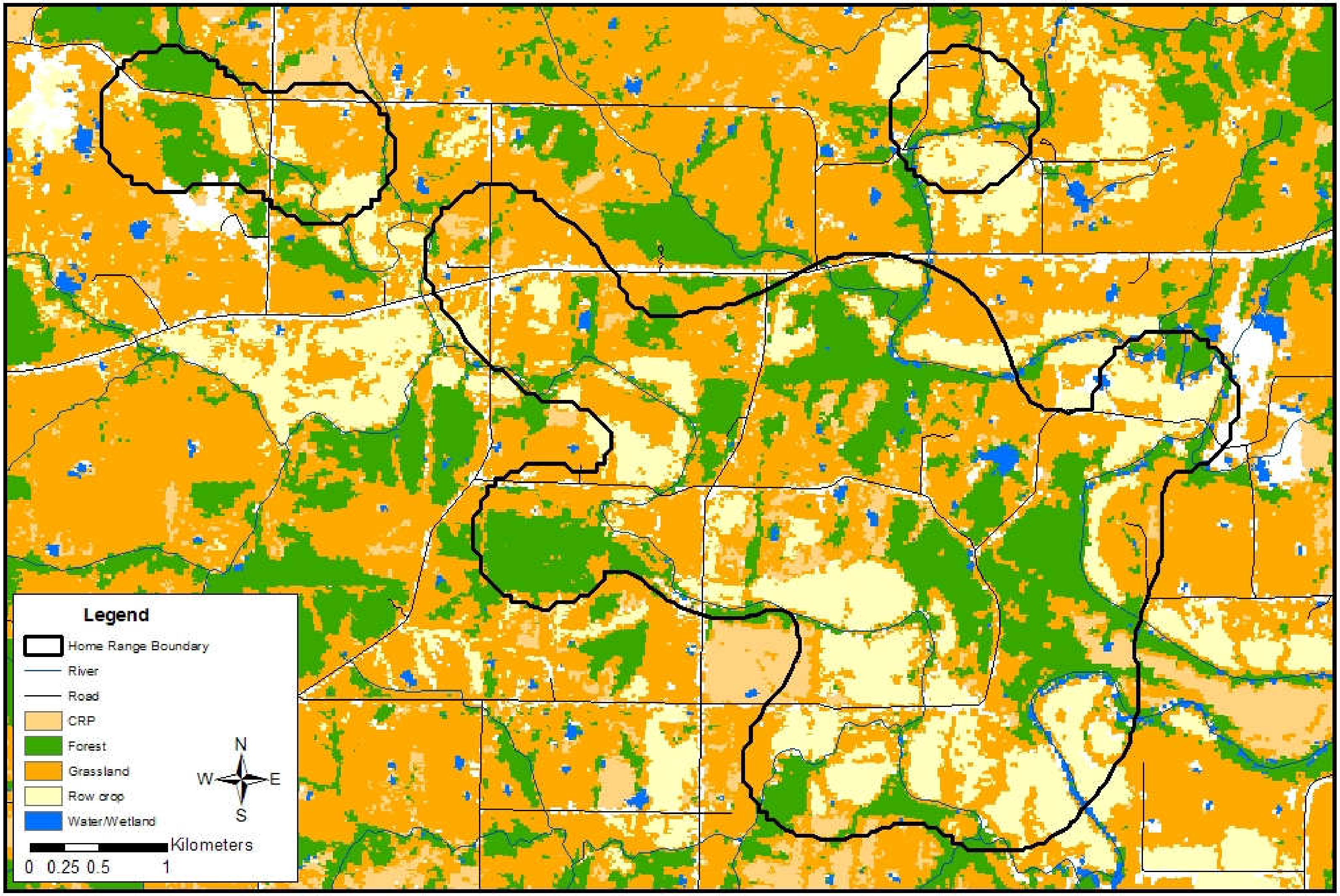

Figure 17. An example of a male bobcat home range (No. 144) with a comparatively high shape index (2.14) in Decatur County, Iowa, 2005.

Table 1. Habitat class descriptions of the Land Cover created from Landsat satellite imagery by the Iowa DNR, Geological Survey, 2002. The original 17 land covers were collapsed into 9 major habitat classes.

Habitat class	Description
Barren	Exposed rock or sand, such as quarries or sandbars
CRP	Unmanaged grasses in heavy stands
Forest	Forested areas including conifers and deciduous trees
Grassland	Ungrazed and grazed grasslands as well as alfalfa fields, road ditches, rural roads and grassy waterways
Urban	Areas of impervious surfaces such as asphalt, concrete, buildings, and parking areas
Road	Major roadways or city streets
Row crop	Row crop agriculture comprised mostly of corn and soybeans
Unclassified	Missing data usually due to clouds or shadows
Water/Wetland	Open water and marsh land containing some vegetation

Table 2. Summary statistics of the habitat variables used to predict the size of bobcat home ranges in south-central Iowa, 2003-2005.

Variables	Units	$\bar{x}$	SD
Stream density (1st, 2nd and 3rd order streams)	km/km^2	1.55	0.54
Density of unpaved roads	km/km^2	1.42	0.35
Mean slope	degrees	4.42	0.68
Patch density	no./100 ha	68.00	13.36
Patch size standard deviation	ha	17.24	11.12
CRP largest patch index*	percent	1.76	1.52
Forest largest patch index*	percent	8.09	6.16
Forest patch size standard deviation	ha	17.94	11.39
Proportion grassland	percent	40.35	7.33
Mean distance between grassland patches	m	41.62	3.47
Row crop largest patch index*	percent	2.65	1.96
Row crop patch size standard deviation	ha	9.72	5.66

*Percentage of the total landscape area comprised by the largest patch.

Table 3. Summary statistics of the habitat variables used to predict the size of bobcat cores in south-central Iowa, 2003-2005.

Variables	Units	$\bar{x}$	SD
Stream density (1^{st}, 2^{nd} and 3^{rd} order streams)	km/km^2	2.60	1.60
Slope standard deviation	degrees	2.72	0.56
Largest patch index*	percent	29.59	15.07
Patch size standard deviation	ha	9.19	5.49
Proportion forest	percent	34.69	14.98
Forest largest patch index*	percent	20.45	16.85
Forest edge density	m/ha	81.95	19.72
Mean forest patch size	ha	4.15	3.67
Grassland patch density	no./100 ha	19.92	7.81
Mean grassland patch size	ha	2.32	1.32
Mean distance between grassland patches	m	43.62	8.42
Row crop patch size standard deviation	ha	4.73	4.51

*Percentage of the total landscape area comprised by the largest patch.

Table 4. Summary statistics of the habitat variables used to predict the shape index of bobcat home ranges in south-central Iowa, 2003-2005.

Variables	Units	Mean	SD
Stream density (1^{st}, 2^{nd} and 3^{rd} order streams)	km/km^2	1.55	0.54
Density of paved roads	km/km^2	0.49	0.50
Density of unpaved roads	km/km^2	1.42	0.35
Mean slope	degrees	4.42	0.68
Patch size standard deviation	ha	17.24	11.12
Aggregation index	percent	85.36	1.61
Mean CRP patch size	ha	0.68	0.33
Forest patch density	no./100 ha	9.96	1.78
Forest largest patch index*	percent	8.09	6.16
Forest edge density	m/ha	78.16	17.03
Row crop edge density	m/ha	39.59	16.15
Row crop patch size standard deviation	ha	9.72	5.66

*Percentage of the total landscape area comprised by the largest patch.

Table 5. Mean home range (95% UD) and core (50% UD) size (km^2) of 32 resident bobcats in south-central Iowa during 2003-2005.

	April-September		October-March		All	
	F	M	F	M	F	M
No. of individuals	15	15	13	12	15	16
No. of UDs*	23	16	20	12	43	28
Mean no. of locations	47	39	37	28	42	33
Mean home range size	15.64	53.92	26.30	57.67	19.90	55.34
Mean core size	1.66	7.62	3.09	9.73	2.22	8.46

*Some UDs were calculated on the same individual in more than one year.

Table 6. MANOVA results for tests of difference between the weighted log-ratios of habitats used by bobcats versus available habitat at 3 scales in south-central Iowa, 2003-2005.

		Wilk's Λ	*P*
Used = home range			
Available = study area			
	F	0.125	< 0.001
	M	0.179	< 0.001
	All	0.177	< 0.001
Used = core			
Available = home range			
	F	0.360	< 0.001
	M	0.371	0.004
	All	0.388	< 0.001
Used = buffered point locations			
Available = home range			
	F	0.101	< 0.001
	M	0.141	< 0.001
	All	0.133	< 0.001

Table 7. Mean habitat class selection ranks in descending order of female and male bobcats calculated by compositional analysis at 3 scales in south-central Iowa, 2003-2005.

	Home range vs. study area		Core vs. home range		Point locations vs. home range	
Habitat class	F	M	F	M	F	M
Barren	0	0	3	1	3	0
CRP	4	4	5	6	2	3
Forest	7	7	7	7	7	7
Grassland	6	6	6	5	6	5
Residential/Industrial	5	3	4	4	4	6
Road	3	5	2	3	0	2
Row crop	2	1	1	2	1	1
Water/Wetland	1	2	0	0	5	4

Table 8. Parameter estimates of the best-fit regression model for predicting the size of bobcat home ranges in south-central Iowa during 2003-2005.

Model parameters	β	SE	t	P
Intercept	3.112	0.213	14.59	<0.001
Sex	0.020	0.109	0.19	0.852
Stream density	-0.409	0.089	-4.61	<0.001
Patch size standard deviation	0.036	0.005	7.26	<0.001
Row crop largest patch index	-0.167	0.028	-6.04	<0.001
Row crop patch size standard deviation	0.075	0.010	7.82	<0.001

Table 9. Akaike's Information Criterion (AIC_C) corrected for small sample sizes, ΔAIC_C, and model weights of the 4 best-fit regression models for predicting the size of bobcat home ranges in south-central Iowa during 2003-2005.

Model	No. Parameters	Parameters	AIC_C	ΔAIC_C	w_i
1	5	Sex Stream density Patch size standard deviation Row crop largest patch index Row crop patch size standard deviation	79.7	0.0	0.802
2	6	Sex Stream density Patch size standard deviation Mean distance between grassland patches Row crop largest patch index Row crop patch size standard deviation	83.7	4.0	0.109
3	6	Sex No. of polygons Stream density Patch size standard deviation Row crop largest patch index Row crop patch size standard deviation	84.1	4.4	0.089
4	5	Sex No. of polygons Patch size standard deviation Row crop largest patch index Row crop patch size standard deviation	99.2	19.5	0.000

Table 10. Parameter estimates of the best-fit regression model for predicting the size of bobcat cores in south-central Iowa during 2003-2005.

Model parameter	β	SE	t	P
Intercept	0.901	0.129	6.97	<0.001
Sex	0.388	0.107	3.62	<0.001
Patch size standard deviation	0.115	0.010	11.30	<0.001
Largest patch index	-0.035	0.003	-10.16	<0.001
Grassland patch size standard deviation	0.016	0.005	3.36	0.001
Paved road density	0.322	0.131	2.47	0.016

Table 11. Akaike's Information Criterion (AIC_C) corrected for small sample sizes, ΔAIC_C, and model weights of the 4 best-fit regression models for predicting the size of bobcat cores in south-central Iowa during 2003-2005.

Model	No. Parameters	Parameters	AIC_C	ΔAIC_C	w_i
1	5	Sex Patch size standard deviation Largest patch index Grassland patch size standard deviation Paved road density	91.9	0.0	0.626
2	6	Sex Patch size standard deviation Largest patch index Grassland patch size standard deviation Paved road density Stream density	93.6	1.7	0.268
3	6	Sex No. of polygons Patch size standard deviation Largest patch index Grassland patch size standard deviation Stream density	96.6	4.7	0.060
4	5	Sex No. of polygons Patch size standard deviation Largest patch index Grassland patch size standard deviation	97.1	5.2	0.047

Table 12. Parameter estimates of the best-fit regression model for predicting the shape index of bobcat home ranges in south-central Iowa during 2003-2005.

Model parameter	*β*	SE	t	*P*
Intercept	1.404	0.175	8.04	<0.001
No. of polygons	0.206	0.029	7.15	<0.001
Sex	-0.144	0.061	-2.38	0.020
Forest patch density	0.034	0.018	1.93	0.058

Table 13. Akaike's Information Criterion (AIC_C) corrected for small sample sizes, ΔAIC_C, and model weights of the 4 best-fit regression models for predicting the shape index of bobcat home ranges in south-central Iowa during 2003-2005.

Model	No. parameters	Parameters	AIC_C	ΔAIC_C	w_i
1	3	No. of polygons Sex Forest patch density	19.2	0.0	0.699
2	4	No. of polygons Sex Forest patch density Density of unpaved roads	21.0	1.8	0.284
3	3	No. of polygons Patch size standard deviation Forest patch density	26.6	7.4	0.017
4	4	No. of polygons Patch size standard deviation Forest patch density Row crop edge density	35.6	16.4	0.000

Table 14. Summary statistics of the habitat variables for each county within the study area.

Variables	Appanoose	Clarke	Decatur	Lucas	Marion	Monroe	Warren	Wayne
Stream density (1^{st}, 2^{nd} and 3^{rd} order streams; km/km^2)	0.92	0.95	0.95	0.90	0.81	0.95	0.81	0.84
Density of unpaved roads (km/km^2)	1.14	1.13	1.07	1.15	1.26	1.00	1.26	1.13
Mean slope (degrees)	3.23	3.81	3.94	3.91	3.36	4.42	3.34	3.10
Patch density (no./100 ha)	58.29	60.33	60.67	60.41	66.08	58.25	58.25	54.19
Patch size standard deviation (ha)	131.31	61.73	120.99	94.33	36.89	68.26	68.26	166.96
CRP largest patch index (%)	0.11	0.40	0.19	0.19	0.08	0.08	0.15	0.18
Forest largest patch index (%)	1.39	0.89	0.47	1.87	0.47	0.93	0.27	0.26
Forest patch size standard deviation (ha)	25.38	15.84	13.41	30.12	13.14	27.36	10.37	7.90
Proportion grassland (%)	46.02	44.59	48.24	45.01	31.85	45.25	38.88	46.60
Mean distance between grassland patches (m)	40.13	39.96	40.03	40.30	40.90	39.90	39.77	40.49
Row crop largest patch index (%)	0.74	0.46	0.56	0.35	2.08	0.77	0.90	0.84
Row crop patch size standard deviation (ha)	28.31	19.23	22.90	18.94	59.95	22.13	25.98	41.76

CHAPTER 3: DEMOGRAPHY OF A RECOLONIZING POPULATION OF BOBCATS (*Lynx rufus*) IN IOWA

A paper to be submitted to the Journal of Wildlife Management

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***Abstract*:** Bobcats (*Lynx rufus*) are recolonizing areas of the Corn Belt region of the Midwest since their disappearance around the late-1970s. To date, no study has examined the demography and dynamics of a recolonizing population of bobcats. In addition, Iowa is agriculturally-dominated landscape resulting in highly fragmented patches of suitable habitats such as forest and grassland. The effect of this type of a landscape on bobcat demography is unknown. We necropsied 265 bobcat carcasses collected from a minimum of 31 Iowa counties. We captured and radio-collared 44 live bobcats from an 8-county study area in south-central Iowa. From these samples we calculated sex ratio, age distribution, reproduction, and survival. The proportion of females in the population (0.46 ± 0.03) did not differ from a 1:1 sex ratio. Mean age was 1.29 ± 0.08 years and the oldest bobcat was aged at 9 years. Bobcats $\leq$2 years of age comprised 66% of the age distribution and bobcats $\geq$5 years comprised 2% of the distribution. Mean litter size as determined from placental scars ranged from 2.50-3.00 and did not differ among age classes. Pregnancy rates of adult females ranged from 0.76-1.00 and did not differ among age classes. One female aged 0-1 years had recent corpora lutea indicating pregnancy at approximately 10 months of age. Annual survival of 44 radio-collared bobcats was 0.82 ± 0.05. There was no difference in survival between study years or sexes. Automobile collisions (33%) accounted for most mortalities with incidental trapping (22%) being the second most common cause of death. Annual survival as calculated from the age distribution (0.56) was considerably lower than that estimated from the radio-collared bobcats. Population growth estimates determined from life table analysis indicated a rate of annual growth (λ) ranging from 1.13-1.52, depending on assumptions. These results indicate that the bobcat population in Iowa is increasing at a relatively high rate. Possible mechanisms enabling this recolonization are high yearling reproduction and high adult survival.

Key words**:** bobcat, demography, Iowa, *Lynx rufus,* population growth, reproduction, survival

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Introduction

At the time of settlement bobcats were widespread in the prairie woodland complexes of the Midwest, but by the late-1970s they were considered rare throughout the Corn Belt region (Deems and Pursley 1978). The disappearance of bobcats from this region has been attributed primarily to an increase in the amount of land converted to agriculture and to unregulated harvest (Rolley 1987, Woolf and Hubert 1998). In 1977 the Iowa Department of Natural Resources (DNR) listed the bobcat as Endangered in the state. For the next several years bobcats were undetectable in Iowa. Subsequently, periodic reports of presence of bobcats in Iowa began to occur with a dramatic increase in these reports since the early-1990s. Based on the increased number of bobcat sightings, incidentally trapped bobcats, and automobile killed bobcats, the species status was changed to Threatened in 2001 and then changed to Protected in 2003. Now researchers in Iowa have been afforded a unique opportunity to study an expanding population of bobcats as they recolonize a former area of their range.

Population models have been used to advance the understanding of ecological mechanisms and population dynamics and for the formulation and implementation of management plans (Knowlton 1972). Population models are a function of demographic parameters such as sex ratio, age distribution, reproduction, and survival, as well as movements such as dispersal (Caughley 1977, Johnson 1982). Thus, a first step towards management of a population is to determine its demography. Estimating the demographic parameters of sparsely distributed and cryptic carnivores such as bobcats is difficult (Sargeant et al. 1998). Direct surveys are nearly impossible, therefore indirect methods, such as carcass collections from trappers and fur dealers, are often the resources by which most demographic information is gathered (Clark and Andrews 1982). In addition, we are able to remotely monitor species such as bobcats via radiotelemetry, providing additional data from which survival and density estimates may be calculated (White and Garrott 1990, Millspaugh and Marzluff 2001).

Although bobcat population dynamics have been examined several times in previous research (Crowe 1975a, Fritts and Sealander 1978, Hamilton 1982, Rolley 1985, Knick 1990, Woolf and Nielsen 2002), they have yet to be determined for a population that is recolonizing a former area of its range. The recolonization of other carnivores into former parts of their historic ranges have been documented for California sea otters (*Enhydra lutris*) off the central coast of California (Lubina and Levin 1988), grey wolves (*Canis lupus*) in northern Montana (Pletscher et al. 1997), brown bears in Scandinavia (Swenson et al. 1995), and black bears (*Ursus americanus*) in eastern Oklahoma (Bales et al. 2005). Pletscher et al. (1997), Swenson et al. (1998), and Bales et al. (2005) examined several aspects of these species' demography and identified potential mechanisms aiding in the population expansions, including high adult survival and increased pregnancy rates. In addition, characteristics of these, and presumably most, expanding populations were a preponderance of females (Pletscher et al. 1997, Bales et al. 2005) and high proportion of young adults (Swenson et al. 1998, Bales et al. 2005).

Iowa and the Corn Belt of the Midwest are agriculturally-dominated landscapes, and it is poorly understood how reproduction and survival of bobcats will be affected by landscape composition and configuration. The high degree of fragmentation created by intensive agriculture could result in increased mortality due to increased risks during movements across habitat openings and roads (Noss et al. 1996, Cain et al. 2003) and decreased reproduction because of a lower density of females on the landscape (Crooks 2002). Nielsen and Woolf (2002) studied the vital rates of bobcats in nearby southern Illinois, where their study sites consisted of 28% row crop agriculture, compared to most counties in Iowa which contain >50% row crop agriculture (Figure 1).

Our objectives were (1) to determine the vital statistics of bobcats including population structure, reproduction, and survival, (2) to develop a life table using the estimated age-specific reproduction and survival, and (3) to use this life table to develop a population projection model and calculate population growth. Our overall goals were to determine the status of bobcats in Iowa (i.e. is the population stable, growing, or declining), and gain an understanding of what mechanisms may be aiding the recolonization of bobcats to Iowa and other regions of the Midwest.

Study area

We trapped and radio-collared bobcats in 8 counties in south-central Iowa (Figure 1). We chose these counties on the basis of the percentage of forest habitat, number of reported bobcat sightings and incidentally-trapped bobcats in recent years, and for logistical reasons. The major habitat types in the study area are grasslands/pastures (43%), row crops consisting primarily of corn and soybeans (22%), and forest (17%). Human population density in the study area averages 11 persons/km^2. Mean road density, including paved and unpaved roads, is 1.22 km/km^2.

Methods

Live-capture and Radiotelemetry

We trapped bobcats using baited box traps, Model #TLT 209.5 (Tomahawk Co., Tomahawk, WI, USA), or #3 Victor Softcatch® traps (Woodstream Corp., Lititz, PA, USA). Additionally, we radio collared bobcats that had been incidentally live-captured by licensed private trappers. We anesthetized the bobcats via an intramuscular injection of Ketamine HCl and Xylazine HCl (5:1, 10 mg/kg). We ear tagged each bobcat with an individual identification number. We estimated the age of each bobcat as either a juvenile or adult based on mass and tooth eruption (Crowe 1975b). We extracted an upper lateral incisor from adult bobcats for a more exact determination of age, and sent them to Matson's Laboratory (Milltown, MT, USA) for cementum analysis (Crowe 1972).

We fitted juvenile bobcats with standard VHF radio collars (Advanced Telemetry Systems, Isanti, MN, USA) equipped with a foam insert to allow for future growth. We fitted adult bobcats with either a standard VHF radio collar (Advanced Telemetry Systems, Isanti, MN, USA; Lotek Wireless, Newmarket, ON, Canada) or a GPS collar (Lotek Wireless, Newmarket, ON, Canada). In all cases, we ensured that the radio collar weighed ≤5% of the individual's body weight. All radio collars were equipped with mortality sensors. Capture and handling procedures were conducted in accordance with Iowa State University Institutional Animal Care and Use Committee protocol (5-03-5447-W).

We conducted radiotelemetry using vehicle mounted yagi antennas arrayed in a null-peak configuration (Samuel and Fuller 1996). We located each bobcat 1-2 times per week, and animals that were missing for ≥ 10 days were located from a fixed-wing aircraft. GPS collared bobcats were located on the same schedule as VHF radio collared bobcats. Upon recovery of a GPS collar, the stored data was downloaded and combined with the triangulated locations.

Carcass Collection

Incidentally-trapped bobcats and automobile killed bobcats were collected statewide by Iowa State University and Iowa DNR personnel. Whenever possible, the date, location, and cause of death were recorded at the time of collection. Carcasses were frozen until they could be necropsied. At the time of necropsy, we determined sex and extracted an upper lateral incisor for cementum analysis. We removed the reproductive tracts (i.e. uterus and ovaries) from all female bobcats and examined them for placental scars or the presence of fetuses. Then, we placed the uteri in a 10% formalin solution for a minimum of 36 hours (Knick et al. 1985) to fix the ovaries. After fixing, we dissected the ovaries and examined them for corpora lutea (Crowe 1975b, Payne 1982).

Data Analyses

Population Structure. We determined the sex ratio, defined as the proportion of females in the population, as indicated by live-capture and carcass samples. We calculated the standard error for the proportion females using simple binomial variance. We used χ^2 analysis to test for a difference in the proportion of females between live-captures and carcasses. If no difference was found, we pooled samples. We also used χ^2 analysis to test for differences in the proportion of females between collection years. We used a test of binomial proportions (i.e. H_o: proportion of females = 0.50) to determine if the sex ratio differed from 1:1. All statistical analyses were calculated using SAS 9.1 software (SAS Institute Inc., Cary, NC, USA).

We also determined the age distribution of the bobcat population as indicated by live-capture and carcass samples. Bobcats were aged to the nearest year class (0-1, 1-2, etc.;

Crowe 1975b). We pooled all individuals aged ≥9 years into a single age class creating 10 total age classes. We used χ^2 analysis to test for differences in the age structure between the live-capture and carcass samples. If no difference was found, we pooled samples for further analyses. We also used χ^2 analysis to test for differences in the age structure between collection years and sexes.

Reproduction. We estimated mean *in utero* litter sizes from counts of placental scars, and mean pregnancy rates from the presence of recent corpora lutea (Crowe 1975b), placental scars, or fetuses (Payne 1982). Although we report counts of corpora lutea for comparative purposes, we did not use these structures for estimates of litter size because they are retained throughout the life of the individual (Duke 1949, Crowe 1975, Beeler 1985). We pooled all estimates for females aged ≥5 years because of small sample sizes, creating 6 total age classes. We only used data from females collected in October-March to meet the assumptions of a prebirthing reproduction history (Noon and Sauer 1992). We compared age-specific litter sizes using analysis of variance and age-specific pregnancy rates using χ^2 analysis. We used the age-specific litter size and pregnancy rate estimates to calculate age-specific fecundity rates (m_x). Fecundity rates were calculated based on the sex ratio as determined above.

Survival. We calculated annual survival (S_x) by 2 methods, from the live-capture and carcass samples. First, we used the Kaplan-Meier survival estimator with staggered entry (Pollock et al. 1989) using Known Fate modeling in program MARK (White and Burnham 1999) for the radio-collared bobcats. We entered each bobcat into the model on the day it was collared and censored bobcats from the analysis that could not be located due to the loss of a signal. Censored individuals were included in the risk set again if they were rediscovered. We analyzed survival on a monthly basis for two years from 1 November 2003 to 31 October 2004 and 1 November 2004 to 31 October 2005. We pooled all age classes for the analysis due to small sample sizes. We used the program CONTRAST (Hines and Sauer 1989, Sauer and Williams 1989) to compare among years and sexes.

Secondly, we calculated age-specific survivorship (l_x) using the age distribution formulated during the population structure analysis. We used a 6 age class structure (i.e. individuals $\geq$5 years of age were combined), so that the l_x estimates could be easily associated with the m_x estimates. We smoothed the age distribution of the population using a spline curve so that l_x decreased logically avoiding difficulties associated with variation in age classes due to small sample size (Caughley 1977). It is likely that bobcats <0.5 years of age would not be represented in a sample derived from automobile collisions or incidental trapping because they are not as mobile as adults and they are still under parental care from their mothers (Blankenship and Swank 1979, Bailey 1979, Parker and Smith 1983, Rolley 1985). In order to account for this possible underrepresentation in our sample, we extrapolated age class 0-1 from the 1-2 age assuming 50% first year survival based on research done by Rolley (1985) in Oklahoma. We then converted l_x to S_x for ease of interpretation and comparability to the radio-collared bobcat estimates.

Population Projection. We used the age-specific m_x and S_x estimates to create a simple life table (Caughley 1977) and derive the population's finite annual growth (λ). We used the PopTools 2.6 extension (Hood 2004) for Microsoft Excel to convert the life table to a prebirthing matrix (Noon and Sauer 1992) and to estimate λ. We calculated λ under 4 different scenarios using S_x estimates from both the radio telemetry and age distribution, and m_x estimates from carcass examinations and those reported from previous literature (Rolley 1985).

Results

Live-capture and Radiotelemetry

We radio collared 44 (19 F, 25 M) bobcats from 3 March 2003 to 6 February 2005 (Appendix A). We triangulated a total of 10,023 locations and recovered an additional 1,399 3-D locations from 7 GPS collars. We experienced 8 radio collar failures (2 F, 6 M), all of which were GPS collars. Two of the failed GPS collars (1 F, 1 M) were recovered at later dates. In addition, 2 males aged 1-2 years and equipped with VHF collars disappeared, and it is unclear whether their disappearance was from dispersal, mortality, or collar failure.

Carcasses Collection

We necropsied 265 bobcat carcasses (Appendix B) collected from a minimum of 31 counties (Figure 2). Causes of death included incidental/illegal trapping (37%), automobile collision (15%), illegal shooting (1%), and no data available (46%). The majority of carcasses (78%) were collected from November-January during months of the open trapping season.

Data Analyses

Population Structure. We estimated the proportion of females in the population to be 0.46 ± 0.03 ($\bar{x}$ ± SE). This proportion did not differ significantly from a 1:1 sex ratio ($Z = -1.12$, $P = 0.26$). We found no difference in the proportion of females between the live-capture (0.45 ± 0.08; $n = 44$) and carcass samples (0.46 ± 0.04; $n = 160$; $\chi^2_1 = 0.01$, $P = 0.93$). We also found no difference in the proportion of females among collection years ($\chi^2_3 = 3.78$, $P = 0.29$; Table 1).

The mean age of 265 live-captures and carcasses based on cementum analysis was 1.29 ± 0.08 years. The proportion of individuals ≤2 years of age in the population is estimated to be 66%, and 2% of the sample was comprised of individuals aged ≥5 years. The oldest bobcat was aged 9-10 years. We found no difference in the age distribution between the live-capture sample ($n = 33$) and the carcass sample ($n = 237$; $\chi^2_7 = 8.87$, $P = 0.26$). We also found no difference in the age distribution among collection years ($\chi^2_{21} = 15.14$, $P = 0.82$; Figure 3) or between sexes ($\chi^2_7 = 8.77$, $P = 0.27$; Figure 4). Therefore, we combined sample types, collection years, and sexes to estimate the final age distribution (Table 2).

Reproduction. We examined 94 female reproductive tracts to estimate age-specific litter size and pregnancy rates. Mean litter size, as determined by placental scars, ranged from 2.50-3.00 kittens per female (Table 3). For those age classes with available information, we found no significant difference in litter size ($F_3 = 1.44$, $P = 0.27$). Pregnancy rates, as indicated by the presence of recent corpora lutea, placental scars, or fetuses ranged from 0.76 among yearlings and approached 1.00 among older animals (Table 3). We noted placental scars in one female aged 0-1 year, which might indicate pregnancy at about 10 months of age. Although this has been reported in previous studies (Crowe 1975b, Fritts and Sealander 1978, Blankenship and Swank 1979, Berg 1979, Johnson and Holloran 1985, Gilbert and Keith 2001), this was the only time that we found any indication of first year females having been reproductively active. We found a significant difference in pregnancy rates among all 6 age classes ($\chi^2_5 = 42.34$, $P < 0.001$) however, when the 0-1 age class was removed from the analysis we found no significant difference in adult pregnancy rates ($\chi^2_4 = 3.34$, $P = 0.50$).

Survival. We used 58 bobcat telemetry encounter histories from 44 live-captured individuals (19 F, 25 M) to model annual survival. We estimated the annual survival of all radio-collared bobcats to be 0.82 ± 0.05. Of 9 known bobcat mortalities (5 F, 4 M) causes of death included 3 automobile collisions, 2 incidental trappings, 1 train collision, 1 illegal shooting, 1 predator, and 1 unknown. Bobcats <1 year of age comprised 3 of the mortalities

(2 F, 1 M). There was no difference in annual survival between years ($\chi^2_1 = 0.004$, $P = 0.95$) or sexes ($\chi^2_1 = 0.014$, $P = 0.91$). Sixteen percent (2 F, 7 M) of the encounter histories were censored due to collar failure or signal loss, although 2 of those individuals (1 F, 1 M) were rediscovered at a later date and entered back into the sample. Results from program MARK indicated that the best estimating model allowed varying survival rates for each month as compared to a constant monthly survival (Figure 5). Survival was lowest during the months of November and December, which coincides with the open trapping season. Another drop in survival was seen during the months of February-June, which coincides with the breeding and kitten-rearing times of the year.

Annual survival values estimated from the smoothed age distribution (Figure 6) were much lower than that estimated from telemetry (Table 4). Weighted average S_x of bobcats between ages 1-2 and 3-4 was 0.56. Small sample size of individuals ≥5 years resulted in low estimates of survival of the older age classes.

Population Projection. We constructed 4 possible population projection scenarios using combinations of survival and fecundity statistics (Table 5) that produced a wide range of estimated λs. When we considered survival from the smoothed age distribution with fecundity determined from our carcass collections $\lambda = 1.29$. The smoothed age distribution combined with fecundity derived from previously reported pregnancy rates resulted in $\lambda = 1.13$. When we considered survival from the radio-collared bobcats with fecundity determined from our carcass examinations $\lambda = 1.52$, whereas combining the telemetry survival with fecundity derived from previously reported pregnancy rates resulted in $\lambda = 1.38$. In all scenarios, λ estimates indicated a substantial increase in population size annually.

Discussion

Population projection models derived from our life table indicate that the population of bobcats in Iowa is growing at a relatively high rate. This finding supports the concept of an expanding population (Knowlton 1972). Previous reports of λs for expanding populations include 1.20 for wolves in Montana across a 13-year period (Pletscher et al. 1997) and 1.11 for black bears in Oklahoma (Bales et al. 2005). Life tables have also been constructed for populations of bobcats in Wyoming (Crowe 1975a), Minnesota (Blankenship and Swank 1979), Michigan (Hoppe 1979) and Oklahoma (Rolley 1985), although λ is seldom reported. Crowe (1975a) reported λs ranging from 0.42-1.65 with mean of 1.02 across 25 years of data indicating a slight annual increase for a bobcat population in Wyoming. Rolley (1983) reported a λ of 0.89 indicating a decrease in the number of bobcats in Oklahoma. Additionally, we analyzed a life table provided by Blankenship and Swank (1979) derived from carcasses collected over 2 years, and estimated a λ of 1.00 indicating, a stable population.

Our estimates of λ may be limited by some of the model parameters, including uncertainty associated with the age distribution, unknown first year survival, and discrepancies between the two survival estimates. An additional disadvantage associated with the population projection models is the assumption that the estimated vital rates are stable (Knowlton 1972, Lambert et al. 2006), and in the case of an expanding population this assumption is almost certainly violated.

One possible mechanism contributing to the high rates of increase seen here is comparatively great reproduction in the 1-2 age class. Our observed pregnancy rate of this age class (0.75 ± 0.10) is considerably higher than those previously reported. In harvested populations, bobcats 1-2 years of age had mean pregnancy rates of 43% in Oklahoma (Rolley

1983), 26% in Nova Scotia (Parker and Smith 1983), 40-48% in Washington (Knick 1985), 55% in Kansas (Johnson and Holloran 1985). Woolf and Nielsen (2002) reported a 43% pregnancy rate of bobcats 1-2 years of age for an unexploited population in Illinois.

Our observed age distribution indicates that the proportion of individuals ≤2 years of age in the population is similar to previous reports for bobcats (Crowe 1975a, Bailey 1979, Blankenship and Swank 1979, Parker and Smith 1983, Rolley 1983). However, it should be noted that the age distribution was formulated from 4 collection years and likely contains biases associated with our sampling methods. Also similar to previous studies (Bailey 1979, Blankenship and Swank 1979, Rolley 1985), the proportion of bobcats 1-2 years of age exceeded that of bobcats aged 0-1 years. Blankenship and Swank (1979) reasoned this may be due to 0-1 year old bobcats being less active and therefore less susceptible to harvest. In addition, bobcats 1-2 years of age are may be overrepresented in our sample because of their inexperience and increased movements during dispersal activities (Anderson 1987). To account for some of these biases, we have adjusted the age distribution to reflect more appropriate numbers using common adjustment methods such as smoothing and extrapolation. Knowlton (1972) stated sampling over a long period of time would result in a representative sample of the more mobile portion of the population and a more accurate age distribution. On the other hand, Begon et al. (1996) stated an accurate age distribution should be from a random sample during a short period of time.

Survival of bobcats in their first year is not known for this particular population, and no studies have directly assessed such rates. Rolley (1983) reported survival of the 0-1 age class to be 0.45, however this observation was derived from a life table where the proportion of individuals in this age class was estimated. Similarly, life tables developed by Crowe (1975a), Blankenship and Swank (1979), and Hoppe (1979) estimated first year survival at

0.67, 0.29, and 0.34, respectively. Direct observations of first year survival are near impossible due to the secretive nature of bobcats, the technology required to assess such a parameter, and the dense habitats bobcats occupy. Elasticity analyses of our life table derived matrices indicate that changes in first year survival would typically have the greatest effect on estimates of λ. Therefore, accurate estimation of this parameter may be critical in determining growth of bobcat populations.

Our radio-collar survival estimates were similar to those reported in an unexploited population in Illinois (0.84, Nielsen and Woolf 2002), and exploited populations in Mississippi (0.80, Chamberlain et al. 1999) and Kansas (0.77, Kamler and Gipson 2004). Other studies have reported annual survival for radio-collared bobcats to be 0.57 in Missouri (Hamilton 1982), 0.56-0.66 in Oklahoma (Rolley 1985), 0.49-0.67 in Idaho (Knick 1990), and 0.62 in Massachusetts (Fuller and Berendzen 1995). Automobile collisions accounted for the highest proportion of deaths, suggesting that high road and rural human population densities, such as that seen in much of the Midwest, may have a significant negative impact on bobcat survival. And although bobcats are protected in Iowa, incidental harvest is still the second greatest cause of mortality.

The difference in survival between the radio-collared bobcats and that estimated from the observed age distribution is substantial. One explanation could be that the biases associated with our age distribution, as previously described, may have underestimated our life table derived survival. Another explanation may be the annual survival of the radio-collared bobcats is overestimated because of lost radio signals (Rolley 1985). Lost radio signals are censored from the analysis in program MARK but assumed alive, when in fact the lost signal may be due to mortality. Continued monitoring of live-captured individuals, as well as the collection of carcasses, will increase sample sizes and likely alter the relationship between these 2 survival estimates.

Management implications

Our observed fecundity and survival estimates indicate bobcats are successfully recolonizing areas of Iowa and are likely to continue to expand. Overall, the demographic parameters in this study are similar to those reported in other states despite high proportions of agriculture on the landscape. However, we believe continued monitoring is needed to reduce some uncertainties associated with the age distribution and survival estimates.

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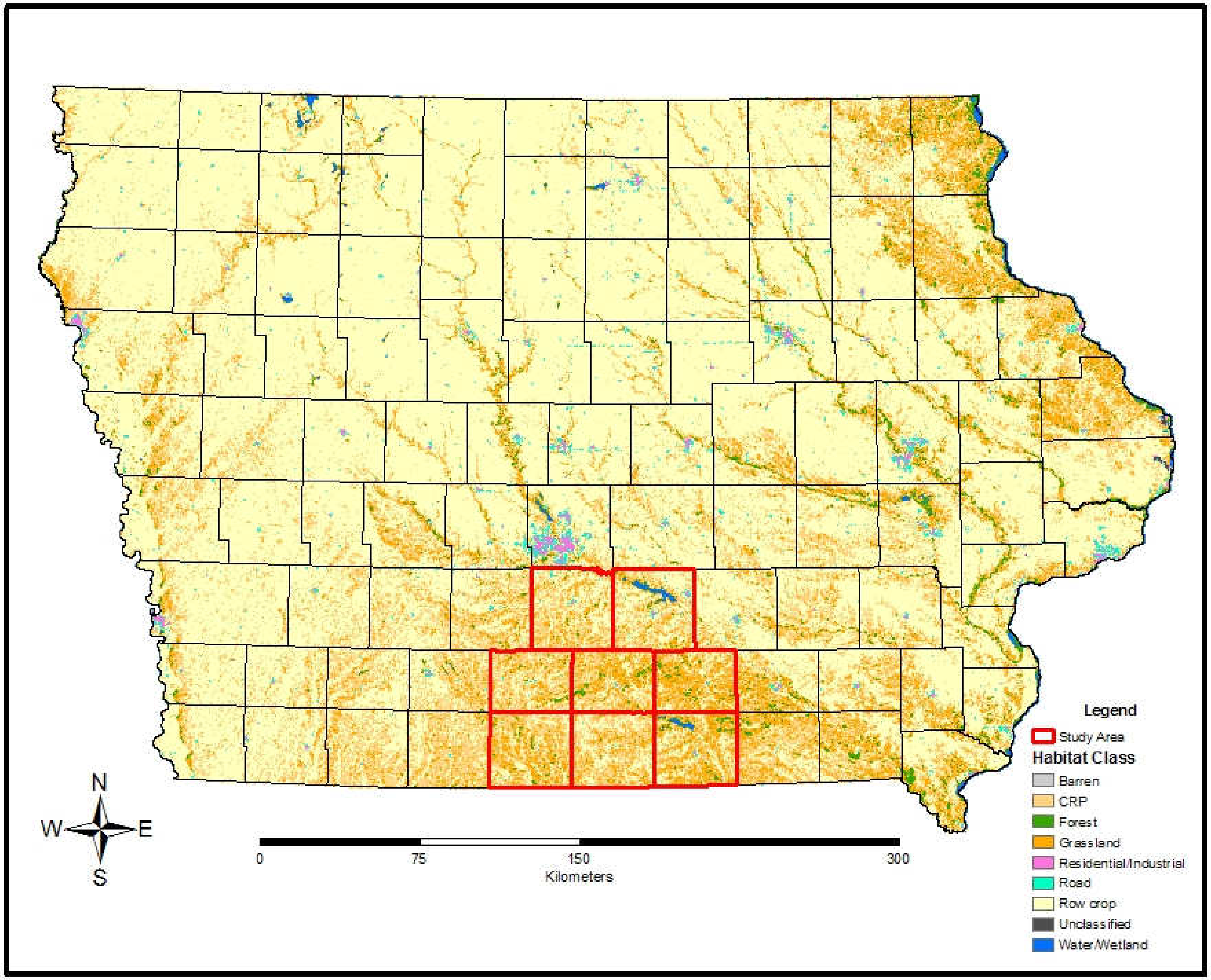

Figure 1. Location of the study area in South-central Iowa where bobcats were actively trapped and radio monitored during 2003-2005. The land cover was created from Landsat satellite imagery by the Iowa DNR, Geological Survey, 2002. The original 17 land covers were collapsed into 9 major habitat classes

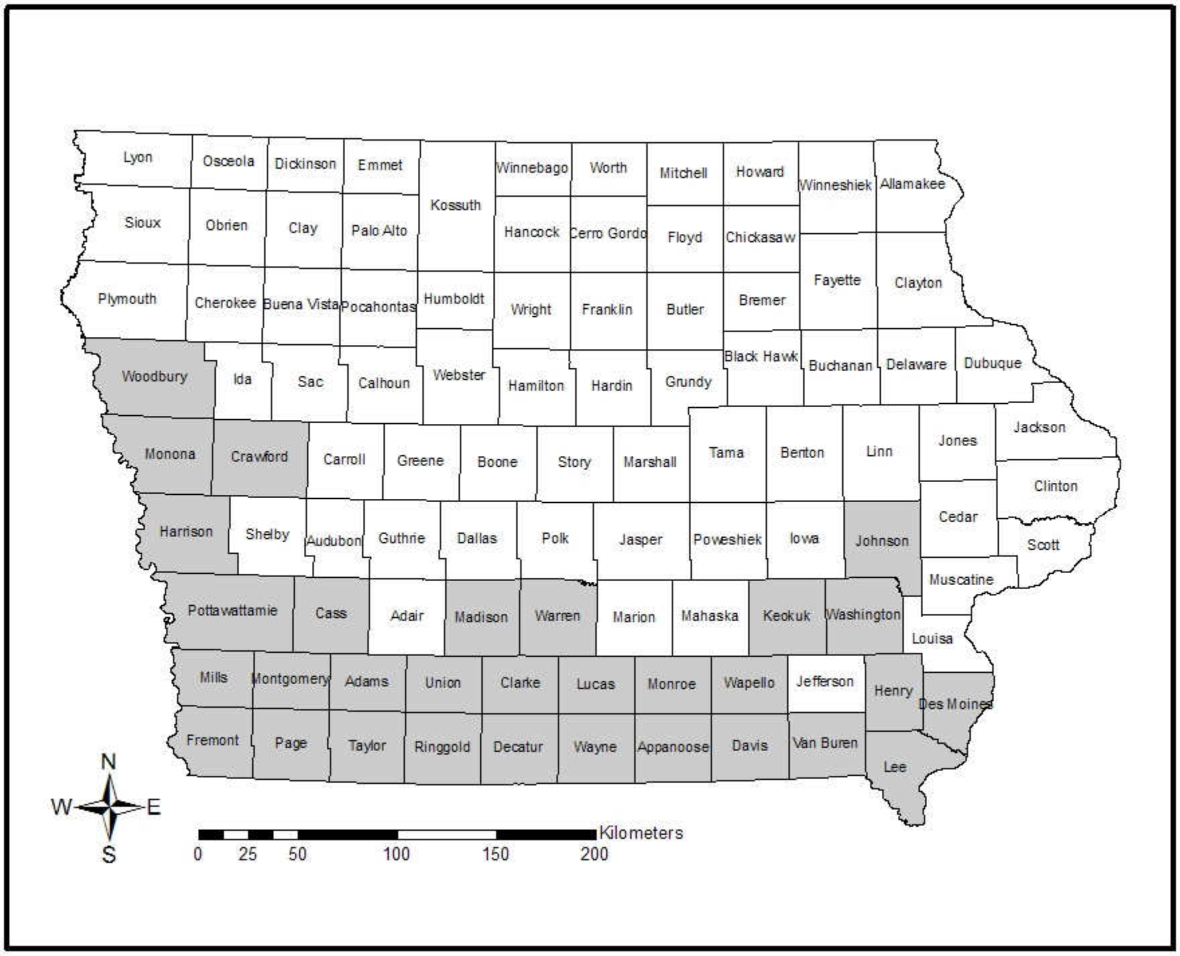

Figure 2. Counties in Iowa where bobcat carcasses have been recovered during 2001-2005.

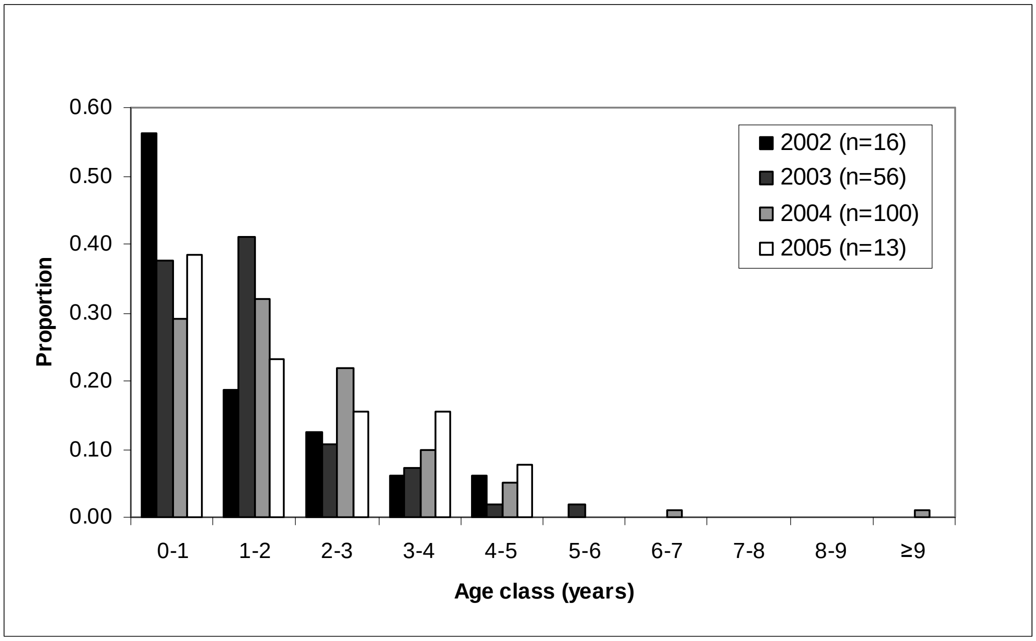

Figure 3. Proportion of bobcats in each age class based on 270 live-captures and carcasses collected in Iowa during 2002-2005.

Figure 4. Proportion of female and male bobcats in each age class based on 265 live-captures and carcasses collected in Iowa during 2001-2005.

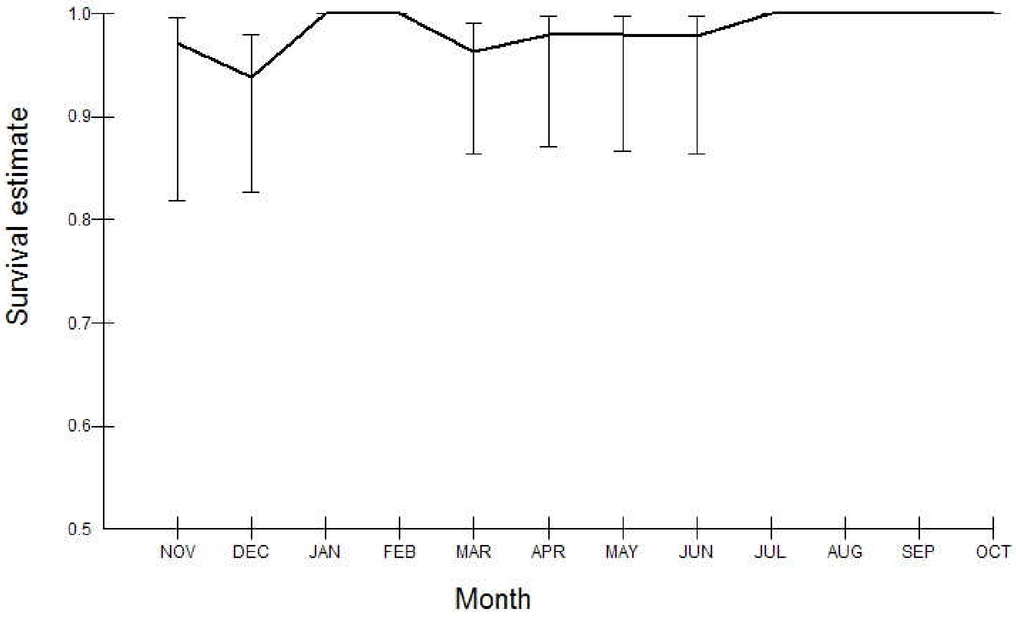

Figure 5. Survival of 44 bobcats calculated in monthly intervals from radiotelemetry observations in Iowa, pooled across 2002-2005.

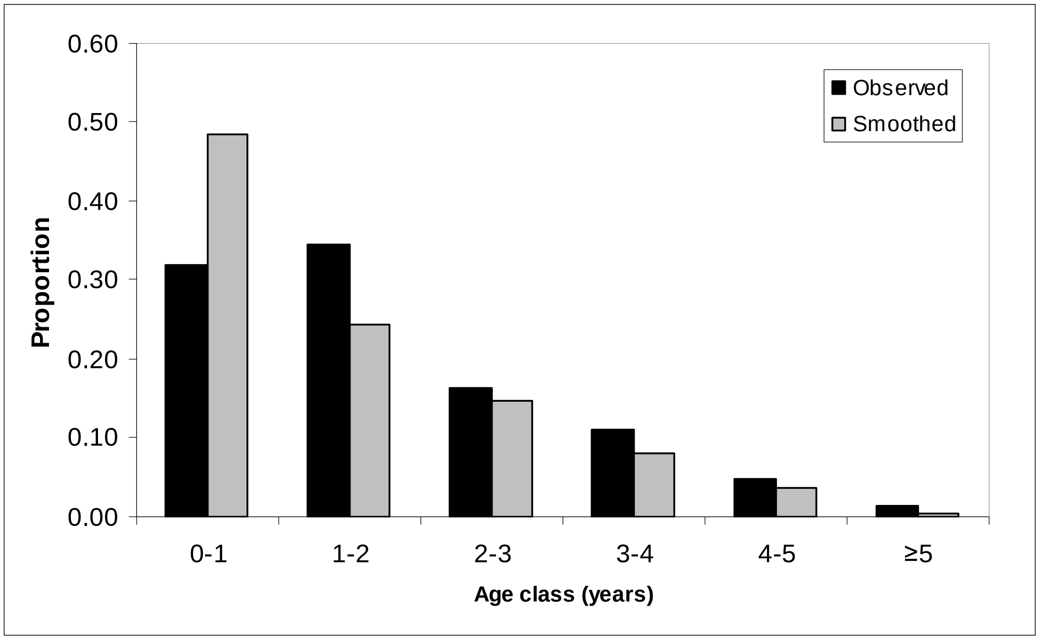

Figure 6. The observed and smoothed age distributions separated into 6 age classes from live-capture and carcass samples collected in Iowa during 2002-2005. The smoothed age distribution was estimated using a spline curve and assuming 50% first year survival (Rolley 1985).

Table 1. Proportion of female bobcats based on 204 live-captures and carcasses collected in Iowa during 2002-2005.

Collection yr	*n*	Proportion of females	SE
2002	16	0.50	0.13
2003	71	0.46	0.06
2004	103	0.49	0.05
2005	14	0.21	0.11
Total	204	0.46	0.03

Table 2. Age distribution of bobcats estimated from tooth cementum analysis of 185 live-captures and carcasses collected in Iowa during 2002-2005.

Age class	*n*	Proportion
0-1	86	0.32
1-2	93	0.34
2-3	44	0.16
3-4	30	0.11
4-5	13	0.05
5-6	2	0.01
6-7	1	0.00
7-8	0	0.00
8-9	0	0.00
≥9	1	0.00
Total	270	1.00

Table 3. Corpora lutea, placental scar, and pregnancy rate estimates of 94 female bobcats collected in Iowa during 2002-2005.

	Corpora lutea			Placental scars			Pregnancy rate		
Age class	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE
0-1	1	4.00		1	3.00		25	0.04	0.04
1-2	7	5.14	0.91	5	3.60	0.24	17	0.76	0.10
2-3	2	5.50	0.50	6	3.50	0.34	8	1.00	0.00
3-4	6	5.17	1.19	6	3.33	0.21	8	0.88	0.12
4-5	1	5.00					1	1.00	
≥5	3	3.67	0.67	2	2.50	0.50	3	1.00	1.00
Total	20			20			62		

Table 4. Life table of bobcats derived from the age distribution and reproductive estimates.

Age class	*n*	l_x	S_x	Litter size[1]	Pregnancy rate	m_x
0-1	174	1.00	0.50	3.00	0.04	0.06
1-2	87	0.50	0.61	3.57	0.75	1.34
2-3	53	0.30	0.55	3.50	1.00	1.75
3-4	29	0.17	0.45	3.33	0.88	1.47
4-5	13	0.07	0.15	0.00	1.00	1.46
≥5	2	0.01	0.00	2.50	1.00	1.25
Total	358					

[1] In order to calculate fecundity, missing litter size values were calculated by averaging across all age classes.

Table 5. Vital statistics of survival and fecundity estimates used to construct 4 possible population projection scenarios for bobcats in Iowa.

		Life table[1]		Telemetry[2]		m_x	
Age Class	*n*	l_x	S_x	l_x	S_x	Observed[3]	Literature[4]
0-1	174	1.00	0.50	1.00	0.50	0.06	0.00
1-2	87	0.50	0.61	0.50	0.82	1.37	0.80
2-3	53	0.30	0.55	0.41	0.82	1.75	1.63
3-4	29	0.17	0.45	0.34	0.82	1.47	1.55
4-5	13	0.07	0.15	0.28	0.82	1.36	1.36
≥5	2	0.01	0.00	0.23	0.82	1.25	1.16

[1] Survival values calculated from observed age distribution.

[2] Survival values calculated from 44 radio-collared bobcats.

[3] Fecundity value derived from observed litter size and pregnancy rate estimates.

[4] Fecundity values derived from observed litter size estimates and pregnancy rates reported by Rolley (1985) in Oklahoma.

CHAPTER 5: GENERAL CONCLUSIONS

Discussion

Iowa is in the center of the most altered, agriculturally-fragmented landscape of the Midwest, and is not typical of most other states where bobcats are found. Large tracts of forest are uncommon creating forest patches which are generally smaller than most bobcat home ranges. Early records indicate that only 38% of the historical 6.5 million acres of forest still remain in Iowa, compared to the late-1800s (Widner 1968). My research emphasizes the importance of these remaining forest patches to bobcats. Compositional analysis revealed that Forest was consistently the most highly selected habitat class, followed by Grassland. Although analysis indicates that bobcats are consistently found in forests, they appear to be selecting forest habitat within their intensive use areas (i.e. cores) that is surrounded by grasslands and CRP. Not surprisingly, row crops appear to be being avoided by bobcats. Forests surrounded by grasslands and CRP likely provide a source of preferred prey such as rabbits and other small rodents (Anderson 1987), escape cover from other predators such as coyotes, and seclusion from human activities.

The benefits of CRP to other wildlife species, especially birds (Clark and Bogenschutz 1999, Reynolds et al. 2001, Johnson and Igl 1995), have been well demonstrated. Although some researchers have suggested that CRP may have been an important factor contributing to the recolonization of bobcats in Iowa, this study has not revealed selection for CRP by itself. In fact, bobcats are using agricultural grasslands managed for grazing and haying in equal or higher proportions than CRP. It appears that the importance of grassland and CRP is the way in which they contribute to the context of the landscapes selected by bobcats. In contrast, annual row crops provide cover for bobcats during the growing season, but not during the non-growing season and prey availability is likely very low. Therefore, it is reasonable to assume that bobcat abundance and occurrence would be limited by the distribution and intensity of row crop agriculture, similar to that reported in southern Illinois (Nielsen and Woolf 2002). I can speculate that bobcat habitat selection is not only influenced by the landscape characteristics, but also by competition with other predators such as coyotes, quality of escape cover, availability of preferred prey, and human disturbance. But the details of these mechanisms need further study.

Landscape fragmentation and configuration are affecting home range and core sizes of bobcats in Iowa, and presumably their distribution and density. Regression models developed with habitat characteristics explain a majority of the variability in home range and core size. Model parameters indicate that unit changes in stream density have the largest affect on home range size, and unit changes in paved road density have the largest affect on core size. As the variability in patch size increased, home range and core sizes increased, whereas they decreased as the amount of the home range or core comprised of a single patch increased. Home range size of bobcats in Iowa is similar to those reported in other areas (Bailey 1974, Hamilton 1982, Rucker et al. 1989, Lovallo and Anderson 1996). However, the home range size of bobcats in Iowa is at the upper limit of previous reports. Bobcats typically exhibit relatively little intrasexual overlap of home ranges (Kitchings and Story 1979, Lovallo and Anderson 1996). Given the social behavior of bobcats, it seems reasonable to assume that the density of bobcats will decrease either as forest and grassland habitat is lost or as these elements become more fragmented by agriculture. Presumably, once a certain threshold of habitat loss and fragmentation is reached bobcats will not be present (Crooks 2002). Fragmentation may also result in lower survival, increased daily energy expenditure, and lower reproductive success but I can only speculate on their potential effects.

Not surprisingly, forest patch density appears to be the most important habitat variable in the determination of home range shape. The effects of fragmentation on home range shape has implications for the trade-offs between the costs of maintaining a particular shaped home range (e.g. circular versus convoluted) and the benefits derived from the home range (e.g. defending only preferred habitats versus defending non-preferred habitats as well). Although it may be argued that the determination of home range boundaries is not an exact science (Powell 2000), it is useful to understand that landscape configuration, particularly forest configuration, influences the spatial arrangement of bobcats on the landscape.

I was unable to make sensible predictions about the size of bobcat home ranges at the county scale, and this finding emphasizes that *a priori* selection at the landscape scale is has occurred when bobcats establish home ranges. The fragmentation and configuration of a landscape within a county is considerably different than that of the landscapes that bobcats occupy. It remains to be determined whether this will be a limitation to further expansion across the state.

My estimates of finite annual increase indicate that the bobcat population in Iowa is growing, consistent with rates characteristic of a recolonizing population. Examinations of carcasses revealed that pregnancy rates of the 1-2 age class in Iowa are substantially higher than previous reports from elsewhere (Rolley 1983, Parker and Smith 1983, Johnson and Holloran 1985, Knick et al. 1985, Woolf and Nielsen 2002). My estimates from radio-collared bobcats also demonstrate high adult survival rates. Together these mechanisms may be the source of the near maximum possible growth rates seen here. As the population density of bobcats increase, pregnancy rates and survival may decrease and eventually stabilize as habitat becomes saturated. Only by continued monitoring would this become evident.

Overall, the demography of bobcats in Iowa is similar to previous reports for the species. Specifically, sex ratio, age structure, litter size, and adult pregnancy rates are comparable to studies conducted in Wyoming (Crowe 1975), Kansas (Johnson and Holloran 1985), Texas (Blankenship and Swank 1979), Oklahoma (Rolley 1983), and Washington

(Knick et al. 1985) indicating that these parameters may be relatively fixed. Discrepancies between the radiotelemetry- and carcass-derived survival estimates need to be resolved, which may be concluded only through increased sample sizes. Currently, it is still unclear if estimates of survival are overestimated by radiotelemetry or underestimated by carcass collections. Kitten survival is also largely unknown, and researchers should attempt to derive more reliable estimates of this parameter.

Previous research suggests that a female-skewed sex ratio (Pletscher et al. 1997, Bales et al. 2005) and a high proportion of young individuals may be characteristic of recolonizing carnivore populations (Swensen et al. 1998, Bales et al. 2005). My observed sex ratio was not skewed toward females. And although my observed age structure (66% ≤ 2 years of age) was similar to previous reports of exploited populations of bobcats (Crowe 1975, Bailey 1979, Berg 1979, Johnson and Holloran 1985, Rolley 1983), it was younger than an unexploited population of bobcats in Illinois (< 50%, Woolf and Nielsen 2002). High adult survival has also been suggested as a mechanism for expansion in wolves (Pletscher et al. 1997), and albeit my estimates of adult survival are also high, they are not outside the range of previous reports (Chamberlain et al. 1999, Kamler and Gipson 2000, Nielsen and Woolf 2002). My research suggests that high pregnancy rates of young adults may be a mechanism of particular demographic significance to this recolonizing population.

Future research should include examination of bobcat dispersal in an agricultural landscape such as Iowa. As bobcats continue to fill the Corn Belt region of the Midwest, knowledge about the dispersal of individuals, particularly juveniles, would help conservationists to better understand how bobcats move through this fragmented landscape. Knowledge about the direction of dispersal events would provide insights as to if and how bobcats will continue to expand and what potential barriers to dispersal may be. This would allow rates of immigration and emigration to be incorporated into population projection models (Knowlton 1972). In addition, the success of dispersers in establishing new territories would give an indication as to whether particular areas will be able to support self-sustaining subpopulations of bobcats. Examination of genetic similarities may be another way of deriving some of these estimates such as immigration and emigration.

The recolonization of bobcats in Iowa following their near extirpation demonstrates the successful conservation of this mid-sized carnivore. Although it appears that bobcats may be in the early stages of recolonization, results from this study are a positive indication that the population is growing and able to sustain itself. Bobcats are capable of using areas with a moderate amount of fragmentation such as that seen in southern Iowa, but forest habitat remains important to bobcats in the Midwest. Whether bobcats will continue to expand their distribution or become more abundant in this region remains to be seen.

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APPENDIX A. SUMMARY OF LIVE-CAPTURE DATA

ID	Capture date	Easting	Northing	Sex	Age	Immo-bilizing agent dose (cc)[a]	Induc-tion time (min)[b]	Rev-ersal agent dose (cc)[c]	Recov-ery time (min)[d]	Total length (cm)	Tail length (cm)	Chest girth (cm)	Height (cm)	Mass (kg)	Trap type
000	3 Mar 2003	451047	4572024	F		1.20	5			91		37		8.0	Box
065	22 Oct 2003	484262	4528185	F	0	0.70				79		33		4.1	Box
075	30 Jul 2003	509978	4559649	F	1	1.00	5			89		37		6.8	Box
101	3 Nov 2003	434859	4512995	F	1	1.00				87		37		8.3	Foothold
102	5 Nov 2003	497120	4546001	F		1.20				80		37		7.3	Box
103	14 Nov 2003	509400	4556300	F		1.00				94		36		7.7	Foothold
104	15 Nov 2003	509724	4556287	M	0	1.00				78		35		5.4	Foothold
105	19 Nov 2003	509724	4556294	M	1	1.75				98		41		11.3	Foothold
106	29 Nov 2003	546716	4510777	M		1.25				98		44		12.0	Snare
107	20 Dec 2003	519272	4551494	M	0	1.00	10	0.50	90	88		31		7.5	Box
108	27 Jan 2004	507698	4519538	F		1.50	16	0.60	40	93	14	48	41	9.1	Snare
109	16 Nov 2004	508230	4542905	F	0	1.00	5	0.55	83	84	15	35	36	5.4	Snare
110	26 Dec 2003	510993	4544917	F		0.50		0.40	195			39		10.3	Snare
111	14 Dec 2003	507587	4519986	M		1.40		0.70		103		41		10.9	Snare
113	17 Nov 2004	508191	4542907	M	0	1.00	6	0.55	40	92	16	35	38	6.1	Foothold
114	21 Nov 2004	414148	4558253	M	2	1.00	5	0.70	77	99	14	47	47	11.8	Snare
115	24 Nov 2004	506052	4565828	M	2	2.00	2	1.00	79	104	15	48	48	11.9	Foothold
116	29 Nov 2004	529555	4519289	M	4	1.75	8	1.10	80	106	16	52	47	15.0	Foothold
118	18 Feb 2004	460782	4547506	M	2	1.00	3	0.50	70	102	15	46	47	11.8	Box
119	12 Nov 2004	421065	4520145	F	1	1.00	4	0.55	21	91	15	39	43	7.4	Snare
120	21 Nov 2004	510663	4554389	F	1	0.75	3	0.40	29	91	14	42	44	9.2	Foothold
121	25 Mar 2003	498497	4542484	M		1.90		0.50		96	15	41		10.0	Box
122	12 Dec 2004	423494	4559512	M	2	1.70	13	0.75	75	112	16	47	49	11.2	Foothold
123	27 Dec 2004	446442	4540994	M	2	1.50	3	0.80	34	106	17	47	49	12.1	Foothold
124	17 Nov 2003	436153	4533456	F		1.00				82		31		5.7	Foothold
125	8 Nov 2003	481716	4548700	F		1.50				86		34		6.5	Box

ID	Capture date	Easting	Northing	Sex	Age	Immobilizing agent dose (cc)[a]	Induction time (min)[b]	Reversal agent dose (cc)[c]	Recovery time (min)[d]	Total length (cm)	Tail length (cm)	Chest girth (cm)	Height (cm)	Mass (kg)	Trap type
126	22 Nov 2003	440181	4535888	F	0	1.40		0.30		84		31		4.3	Foothold
127	22 Nov 2003	440181	4535888	M	0	1.50		0.30		86		32		5.7	Foothold
128	8 Dec 2003	418942	4553519	F	2	1.00		0.23		92		37		8.8	Snare
129	16 Dec 2004	428900	4512149	M	4	2.00	3	1.10	10	94	13	49	51	12.9	Snare
130	17 Dec 2004	521480	4523086	M	1	1.50	1	0.80	9	104	16	46	47	12.0	Foothold
136	12 Dec 2003	448497	4540110	F	0	1.10				84		38		6.4	Foothold
137	11 Dec 2003	448337	4539927	F	2	1.00		0.50	90	94		40		9.8	Foothold
138	29 Dec 2004	418603	4510623	F	1	1.50	4	0.80	65	92	14	41	46	8.8	Snare
139	31 Dec 2004	534182	4524654	M	0	0.80	3	0.45	34	88	16	35	40	5.8	Foothold
140	14 Jan 2005	450737	4536387	F	1	1.10	3	0.62	60	95	15	39	46	8.6	Foothold
141	25 Jan 2005	399320	4536918	M	2	1.00	5	0.66	24	105	12	43	51	12.8	Snare
142	27 Jan 2005	399506	4536955	M	0	1.00	3	0.57	34	83	10	36	41	7.5	Snare
143	24 Dec 2004	532162	4517725	M	0	1.00	8	0.55	55	89	15	37	43	7.2	Foothold
144	25 Dec 2004	428407	4512160	M	1	1.00	5	0.53	32	98	15	42	48	11.0	Foothold
146	27 Dec 2004	418604	4510627	M	2	1.00	5	0.40	35	100	18	44	49	11.3	Snare
149	2 Jan 2005	509916	4557385	M	2	1.80	15	0.90	50	95	15	34	47	10.3	Foothold
150	1 Jan 2005	532483	4522031	M	0	1.00	8	0.70	25	80	15	34	40	6.3	Foothold
157	6 Feb 2005	477878	4534021	M	0	1.00	5	0.60	27	88	16	38	44	7.3	Foothold

[a] Ketamine HCl and Xylazine HCl (5:1; 10 mg/kg) mixture administered intramuscularly.

[b] Amount of time (min) from last injection of immobilizing agent until head down and unresponsive.

[c] Yohimbine (0.125 mg/kg) administered intravenously.

[d] Amount of time (min) from reversal injection until reactive and mobile.

APPENDIX B. SUMMARY OF CARCASS DATA

ID	Collection date	Sex	Age	Total length (cm)	Tail length (cm)	Chest girth (cm)	Height (cm)	Mass (kg)	Cause of death	County
001		F	3	88	13	37	41	6.9	Unknown	
002	Nov 2002	F	0	66	9	25	31	2.7	Unknown	Clarke
003	25 Oct 2003	M							Unknown	Fremont
004	10 Jan 2003	M	3	103	16	50	48	13.2	Unknown	
005	12 Nov 2003	M	3	88	14	32	36	4.5	Trap	Monroe
006	3 Aug 2003	M	1	98	15	45	53	11.4	Automobile	
007	Jan 2003	F	1	93	15	36	41	7.4	Trap	Fremont
008		M	3	96	17	52	50	13.4	Unknown	
009		F	1	93	16	40	44	8.1	Unknown	Page
010		F	1	90	12	38	43	7.4	Unknown	Page
011	1 Dec 2003	M							Trap	Johnson
012	27 Dec 2003	M	5	105	17	50	51	14.4	Trap	Union
013	10 Nov 2003	M	0	90	14	36	43	6.3	Trap	Decatur
014		M	2	98	14	47	50	11.2	Unknown	
015		M	4	101	15	46	48	11.4	Unknown	
016	Nov 2003	M	1	97	16	40	46	9.2	Trap	Page
017	10 Dec 2003	F	0	76	12	29	37	4.2	Trap	Appanoose
018	10 Dec 2003	M	3	97	16	44	39	11.2	Trap	Appanoose
019		F	3	91	13	43	40	7.4	Unknown	Taylor
020		M	1	96	15	44	48	10.1	Unknown	
021		F	0			37	41	6.2	Unknown	Decatur
022	Dec 2002	M	1	106	16	48	49	12.3	Unknown	Page
023	19 Nov 2003	M	2	107	17	53	48	14.7	Trap	Davis
024	Nov 2002	M	4	107	15	49	48	13.4	Unknown	
025	Nov 2003	M	1	98	16	45	47	10.3	Trap	Page
026	5 Nov 2003	F							Trap	Henry
027	11 Aug 2003	M							Automobile	Warren
028		M	0						Unknown	
029		M	0	74	13	31	32	5.1	Unknown	
030	2003	M	0	77	13	27	31	3.4	Trap	Page
031	Nov 2002	F	0		11	27		2.4	Automobile	Clarke
032	20 Nov 2003	M	0	72	14	32	33	4.0	Trap	Decatur
033	Nov 2002	M	0	83	16	31	37	3.8	Automobile	Mills
034		F	0	74	12	26	34	3.2	Unknown	
035	19 Dec 2003		0			24			Unknown	Clarke
036		M	0	61	10	27	28	2.5	Unknown	
037	10 Nov 2002	F	0	66	11	27	30	3.3	Unknown	
038	6 Oct 2003	M	2		17				Trap	Appanoose
039	Nov	M	0	82	15	32	39	5.6	Trap	Page
040	Nov 2003	F	1	91	16	33	38	5.8	Trap	Page
041	Nov 2002	M	3	98	14	38	47	9.7	Automobile	Decatur
042	Nov 2003	M	0	82	15	28	37	4.6	Trap	Page
043	Nov 2003	M	0	86	16	31	39	5.5	Trap	Page
044		M	0	88	15	38	39	7.4	Unknown	
045	3 Jan 2004	F	3	90	11	41	42	9.1	Trap	Page

ID	Collection date	Sex	Age	Total length (cm)	Tail length (cm)	Chest girth (cm)	Height (cm)	Mass (kg)	Cause of death	County
046	Dec 2002	M	2	98	15	46	47	10.4	Unknown	Decatur
047		M	1	101	16	49	49	11.9	Unknown	
048	20 Dec 2003	F	1	86	13	36	41	6.3	Unknown	Page
049	26 Nov 2003	F	1	89	12	41	43	8.6	Automobile	Lucas
050		M	1	43	11	40	46	10.2	Unknown	
051	Jan 2003	M		104	14	48	48	12.4	Trap	Fremont
052	27 Dec 2001	M	1	96	14	46	48	12.0	Trap	Henry
053		F	5	89	14	39	44	8.3	Unknown	Taylor
054		F	1	90	13	39	43	6.9	Unknown	
055		F	1	96	15	40	42	7.4	Unknown	
056		F	0	83	12	34	42	5.2	Unknown	Page
057	18 Nov 2003	F	1	90	13	40	42	8.4	Trap	Decatur
058	Dec 2002	F	0	83	12	36	37	5.0	Unknown	Page
059	6 Nov 2003	F	0	84	15	31	36	4.4	Unknown	Page/Taylor
060	3 Aug 2002	M	1						Automobile	Des Moines
061	12 Nov	M	1	94	13	41	45	8.6	Unknown	Lucas
062		M	1	101	16	44	46	10.0	Unknown	
063		M	2	109	16	49	47	13.0	Unknown	
064		M	0	89	16	43	45	7.8	Unknown	
065	26 Nov 2003	M	0	84	13	37	38	5.6	Trap	Lucas
066	6 Nov 2003	M	1	102	15	38	48	12.4	Unknown	Page
067	Nov 2003	F	0	66	10	27	31	2.7	Trap	Page
068	30 Dec 2003	F	1	87	14	38	41	7.2	Trap	Warren
069		M	2	105	14	38	49	6.8	Unknown	
070	16 Dec 2003	F	3	87	13	44	41	8.8	Shot	Monroe
071		M	0	75	12	35	35	5.2	Unknown	Clarke
072	4 Dec 2003	M	1	94	15	43	42	9.8	Trap	Wayne
073	Jan 2004	M	0	76	13	31	36	4.5	Trap	Page
074	19 Dec 2003	M	1	101	16	39	44	10.2	Trap	Lucas
075	24 Nov 2001	F	9	100	16	41	44	9.1	Trap	Des Moines
076	Nov 2003	M	2	105	18	44	48	11.8	Trap	Page
077	7 Nov 2002	F	0	72	11	31	34	5.0	Trap	
078		M	1	99	15	46	48	11.6	Automobile	
079	4 Oct 2001	M		92	13	42	45	10.2	Automobile	Des Moines
080	2003	F	1	91	16	35	41	7.0	Trap	Page
081	Nov 2003	M	0	84	14	31	35	5.6	Trap	Page
082	4 Jan 2003	M	1	100	16	39	42	8.4	Trap	Des Moines
083	Nov	F	0	76	12	28	31	4.2	Unknown	Fremont
084		F	0	79	13	35	38	5.8	Unknown	
085	3 Jan 2003	F	1	96	12	37	47	8.2	Unknown	Taylor
086		M	0	69	12	28	34	4.0	Unknown	
087	7 Nov 2003	M	1	102	17	43	48	11.4	Unknown	
088	7 Nov 2003	F	4	91	12	38	44	8.6	Unknown	Page
089		M	1	96	15	37	39	7.8	Unknown	
090	2003	F		93	14	36	40	8.2	Trap	Page
091	Nov 2003	F	0	79	12	33	36	5.2	Trap	Page
092		F	0	67	11	24	31	2.8	Unknown	

ID	Collection date	Sex	Age	Total length (cm)	Tail length (cm)	Chest girth (cm)	Height (cm)	Mass (kg)	Cause of death	County
093		M		76	13	33	33	4.8	Unknown	
094	16 Nov 2003	M	1	102	15	46	44	11.0	Automobile	
095		F	2	88	13	35	41	6.6	Unknown	
096	Nov 2003	M	0	78	14	33	36	5.0	Trap	Page
097	Nov 2002	M	1	109	15	52	45	13.4	Unknown	Decatur
098		M	2	101	15	40	44	10.2	Unknown	
099		F	0	81	13	36	38	5.7	Unknown	
100	Dec 2002	F	0	86	12	38	39	7.0	Unknown	Decatur
101	Dec 2002	F	2	92	13	37	41	7.0	Unknown	Decatur
102	Dec 2002	M	0	81	14	29	36	4.0	Unknown	Decatur
103		F	3	93	16	43	45	8.3	Unknown	Decatur
104		M	1	95	14	39	44	7.8	Unknown	
105	2 Feb 2003	F							Unknown	Woodbury
106		M							Unknown	Woodbury
107	16 Jan 2003	F	0	80	13	28	35	4.4	Unknown	Wayne
108		M	1	106	19	49	44	11.8	Unknown	
109	14 Dec 2003	M	2	102	16	44	44	12.0	Trap	Van Buren
110		M	1	97	17	45	45	9.0	Unknown	
111	26 Nov 2003	M	2	105	18	44	47	11.6	Trap	Woodbury
112		F	1	83	14	34	36	7.1	Unknown	
113	21 Mar 2003	M	0	99	18	37	45	8.1	Automobile	Decatur
114	10 Nov 2003	F	1	88	14	39	42	8.0	Trap	Decatur
115	11 Feb 2004	M	3	96	15	43	44	12.4	Automobile	Wapello
116	20 Mar 2003	M	1	91	15	35	44	7.8	Trap	Clarke
117	13 Apr 2004	F	1	79	12	32	39	6.0	Automobile	Wayne
118	Jan 2004	M	4	99	14	46	46	9.6	Trap	Page
119	8 Mar 2004	M			18	40	40	7.6	Automobile	Davis
120	29 Feb 2004	F	0	88	13	38	39	7.7	Automobile	Lucas
121		F	2			33		7.3	Unknown	
122		F	2	82		33		6.3	Unknown	
123		F	3	93		36		9.5	Unknown	
124		M	3	92		36		8.3	Unknown	
125		M	1	102		39		10.5	Unknown	
126		F	1	83		31		5.8	Unknown	
127		M	3	103		39		12.0	Unknown	
128		F		76		27		4.8	Unknown	
129		F	0	83		33		6.0	Unknown	
130		M	1	98		37		10.3	Unknown	
131		M	1	101		41		12.3	Unknown	
132		M		82		30		5.3	Unknown	
133		F		75		26		4.5	Unknown	
134		M	4	105		42		12.8	Unknown	
135		M	1	106		43		11.3	Unknown	
136		M		93		36		9.5	Unknown	
137		F		79		33		5.5	Unknown	
138		M	1	90		40		8.8	Unknown	
139		F	1	92		33		8.3	Unknown	Clarke

ID	Collection date	Sex	Age	Total length (cm)	Tail length (cm)	Chest girth (cm)	Height (cm)	Mass (kg)	Cause of death	County
140		F	1	87		32		7.0	Unknown	
141		M	3	93		43		11.0	Unknown	
142		M		99		41		11.3	Unknown	Mills
143		F	2	98		35		8.0	Unknown	
144		F	2	90		40		9.8	Unknown	
145		M		99		42		11.3	Unknown	
146		F		75		31		5.0	Unknown	
147		M	2	96		45		11.3	Unknown	
148		F	2	88		40		9.0	Unknown	
149		M	1	90		36		8.5	Unknown	
150		F	3	96		38		9.0	Unknown	
151		F	3	89		39		9.3	Unknown	
152		M	3	70		25		3.8	Unknown	
153		M		103		42		12.5	Unknown	
154		F		91		31		6.0	Unknown	
155		M	1	90		35		8.8	Unknown	
156	22 Sep 2004	F	1	93	15	39	42	7.5	Automobile	Decatur
157	7 Sep 2004	F	1	90	14	41	43	8.0	Automobile	Davis
158	3 Nov 2004	M	0	78	13	32	37	4.3	Automobile	Clarke
159	10 Nov 2004	F	3	96	15	41	42	9.0	Trap	Decatur
160	10 Nov 2004	M	4	104	17	49	49	14.2	Trap	Decatur
161	14 Nov 2004	F		92	13	42	43	7.8	Trap	Decatur
162	11 Nov 2004	F	0	78	13	31	35	3.6	Trap	Lucas
163		M	0	79	10	35	41	5.2	Unknown	
164	9 Nov 2004	M	2	96	17	44	44	9.2	Unknown	Ringgold
165	9 Nov 2004	F	0	78	14	32	36	4.9	Trap	Davis
166	17 Oct 2004	M	1	91	14	39	44	7.2	Automobile	Lucas
167	12 Nov 2004	M	1	95	15	38	46	7.8	Trap	Davis
168	15 Oct 2004	M	1	102	15	42	47	10.0	Automobile	Washington
169	22 Nov 2004	F	3	89	12	39	42	7.4	Trap	Decatur
170	29 Nov 2004	M	3	100	17	44	49	11.8	Trap	Lucas
171	4 Dec 2004	F	3	96	16	40	43	8.2	Trap	Lucas
172	13 Dec 2004	F	1	92	16	42	44	7.7	Trap	Warren
173	28 Dec 2004	F	0	71	11	28	36	3.4	Trap	Lucas
174	Dec 2004	M	2						Shot	Lucas
175	28 Dec 2004	M	1						Unknown	Wayne
176	2 May 2004	M	2	105	15	46	48	12.0	Trap	Warren
177	22 Nov 2004	F	0	78	14	30	39	5.0	Trap	Lucas
178		M	4	100	17	50	47	13.0	Unknown	Taylor
179	24 Oct 2004	M	1	97	16	47	44	10.0	Automobile	Madison
180	17 Nov 2004	F	2	89	12	37	41	7.8	Trap	Clarke
181	24 Nov 2004	M	2	105	16	45	50	11.8	Trap	Union
182	Nov 2004	M	2	95	15	41	48	10.2	Trap	Fremont
183	22 Nov 2004	M	0	80	14	34	36	12.5	Automobile	Clarke
184	10 Jan 2004	M	0	75	8	32	40	5.8	Automobile	Lee
185		M	3	101	15	46	45	11.4	Unknown	
186	24 Dec 2004	F	0	83	14	30	40	4.8	Trap	Monroe

ID	Collection date	Sex	Age	Total length (cm)	Tail length (cm)	Chest girth (cm)	Height (cm)	Mass (kg)	Cause of death	County
187	12 Nov 2004	M	2	98	14	45	46	11.0	Trap	Fremont
188	Dec 2004	F	3	92	15	36	45	8.4	Trap	Fremont
189	20 Mar 2004	M	1	92	14	43	40	9.0	Automobile	Henry
190	10 Dec 2004	M	0	64	10	28	28	3.4	Trap	Adams
191	22 Nov 2004	F	1	94	14	36	39	7.5	Trap	Wayne
192	18 Oct 2004	F	1	98	15	38	46	8.2	Automobile	Monona
193	5 Sep 2004		2	92	14	38	43	7.6	Automobile	Van Buren
194	29 Nov 2004	F	0	59	8	26	30	2.3	Unknown	Adams
195	21 Dec 2004	F	0	81	14	31	36	5.0	Trap	Page
196		F	0	76	12	31	36	4.4	Unknown	
197	9 Nov 2004	M	0	80	10	31	37	5.2	Trap	Lee
198	21 Dec 2004	F	0	80	12	28	35	4.0	Trap	Page
199		F	4	88	15	44	39	7.2	Unknown	Van Buren
200	Dec 2004	M	0	83	13	33	38	4.4	Trap	Fremont
201		M	0	70	10	33	32	4.0	Unknown	
202		F	0	87	13	31	34	6.0	Automobile	Cass
203	4 Jan 2005	F	3	95	15	41	43	8.3	Trap	Page
204	25 Dec 2004	F	1	89	12	41	43	8.2	Trap	Page
205	7 Nov 2004	M	0	86	15	38	44	6.8	Unknown	
206	12 Nov 2004	M	1	105	15	45	50	11.2	Automobile	Johnson
207	Dec 2004	F	1	90	13	41	40	7.2	Trap	Montgomery
208	19 Nov 2004	M	0	88	14	35	40	6.4	Automobile	Appanoose
209	25 Feb 2005	M		98	14	46	45	9.6	Unknown	Monroe
210	11 Oct 2004	M	4	106	15	56	50	14.8	Trap	Monona
211		M	1	94	14	49	49	12.5	Unknown	
212	14 Feb 2005	M	1	96	17	38	46	8.1	Automobile	Montgomery
213	Dec 2004	M	1	100	16	44	50	11.0	Trap	Page
214		F	0			28	33	2.5	Unknown	
216	19 Mar 2005	M	3	93	14	42	45	12.5	Automobile	Lucas
217		F	1	89	14	40	41	8.2	Unknown	
218	15 Nov 2004	F	1	94	14	42	43	9.4	Trap	Ringgold
219		M	1	94	16	41	46	9.0	Unknown	
220		F	1	85	14	39	41	8.4	Unknown	
221		F	1	88	13	40	42	8.4	Unknown	Fremont
222	16 Feb 2005	M	4	105	17	47	50	15.0	Automobile	Davis
236	16 Dec 2004	M	1	91	12	46	47	11.0	Trap	Decatur
237	17 Nov 2004	F	3	94	13	39	45	8.2	Trap	Harrison
238	13 Nov 2004	F	2	99	14	40	44	8.6	Trap	Henry
239	13 Jan 2005	F	0	90	12	36	41	6.6	Trap	Page
240	8 Jan 2005	M	0	93	14	34	44	7.2	Trap	Page
241	10 Jun 2004	F	0	89	12	37	39	6.6	Automobile	Decatur
242		F	2	97	14	37	43	8.0	Trap	Adams
243	12 Nov 2004	F	2	94	13	35	42	6.6	Trap	Page
244	2 Nov 2004	M	1	93	14	41	45	8.6	Automobile	Pottawattamie
245		M	1	94	15	42	46	9.4	Unknown	
246	26 Nov 2002	F	0	53	8	27	26	2.0	Unknown	
247	23 Oct 2004	F	0	72	13	34	33	4.0	Automobile	Fremont

ID	Collection date	Sex	Age	Total length (cm)	Tail length (cm)	Chest girth (cm)	Height (cm)	Mass (kg)	Cause of death	County
248	2 Apr 2004	M	1	89	14	43	46	9.6	Automobile	Lee
249	15 Feb 2005	M	1	93	10	46	48	11.6	Trap	Adams
250	15 Nov 2004	F	0	72	14	31	34	3.4	Trap	Monona
251		M	1	100	16	46	50	11.4	Shot	Wapello
252	13 Nov 2004	F	0	61	12	29	29	2.6	Trap	Henry
253		M	0	88	15	40	39	6.4	Unknown	
254	6 Aug 2004	M		47	7	21	21	1.0	Unknown	Wayne
255	10 Nov 2004		3						Trap	Monona
256	25 Dec 2004	M	0	69	10	29	34	2.8	Unknown	Decatur
257	19 Dec 2004	M	3	105	17	49	48	13.0	Trap	Decatur
258	19 Nov 2004	F	6	93	15	36	40	7.2	Trap	Van Buren
259	5 Nov 2004	F	2	92	12	35	0	8.2	Unknown	Ringgold
260	18 Jun 2004	F	1	95	14	33	42	6.0	Automobile	Clarke
261	10 Apr 2004	F	0	82	13	7	34	3.8	Trap	Page
263	Nov 2004		0	90	13	39	40	6.6	Automobile	Van Buren
264	2 Feb 2004	M	0	78	12	29	37	5.0	Automobile	Woodbury
265	23 Oct 2004	M	2	102	16	41	47	11.8	Trap	Page
266	24 Dec 2004	M	1	97	13	38	48	10.0	Unknown	Fremont
267	18 Dec 2004	F	1	91	15	35	41	7.2	Trap	Des Moines
268	11 Dec 2004	F	9	90	13	36	40	8.0	Trap	Taylor
269	28 Nov 2004	M	1	99	14	35	46	9.6	Trap	Davis
270	29 Nov 2004	F	2	89	13	33	4	7.0	Trap	Page
271	Dec 2004	F	2	91	14	33	40	7.2	Trap	Fremont
272	18 Dec 2004	F	2	85	3	36	45	8.6	Trap	Crawford
273		M	3	108	17	43	48	13.2	Unknown	
274		M	4	104	14	41	52	13.2	Unknown	
275	9 Nov 2004	M	1	101	15	36	45	9.2	Trap	Keokuk
276	27 Nov 2004	F	2						Trap	Monona
277	22 Dec 2004	F	1	91	14	32	41	7.0	Trap	Fremont
278	5 Dec 2004	F	1	96	15	34	46	7.4	Trap	Woodbury
279	30 Dec 2003		1						Automobile	Des Moines
280	8 Oct 2004	F							Automobile	Woodbury

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