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Evaluation of Bobcat (Lynx rufus) Survival, Harvest, and Population Size in the West-Central Region of South Dakota

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EVALUATION OF BOBCAT (*Lynx rufus*) SURVIVAL, HARVEST, AND POPULATION SIZE IN THE WEST-CENTRAL REGION OF SOUTH DAKOTA

BY

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EVALUATION OF BOBCAT (*Lynx rufus*) SURVIVAL, HARVEST, AND POPULATION SIZE IN THE WEST-CENTRAL REGION OF SOUTH DAKOTA

This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science in Wildlife and Fisheries Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidates are necessarily the conclusions of the major department.

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EVALUATION OF BOBCAT (*Lynx rufus*) SURVIVAL, HARVEST, AND POPULATION SIZE IN THE WEST-CENTRAL REGION OF SOUTH DAKOTA

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Recent concern regarding bobcat (*Lynx rufus*) population status has prompted researchers and managers to gather additional information about bobcats in South Dakota. From 2012–2015, we assessed population dynamics of bobcats occupying the west-central region of South Dakota. Our objectives were to: 1) estimate annual survival rates; 2) determine cause-specific mortality; 3) estimate a population size for the western prairie region of South Dakota; 4) estimate home range size of individually marked bobcats; 5) evaluate reproductive status; and 6) build a population model. We captured and radio-collared 51 (24 male, 27 female) bobcats with VHF collars. Annual survival was 65.1% (95% CI = 35.9–86.2%) in 2013–2014, 75.9% (95% CI = 57.4–88.0%) in 2014–2015, and 71.5% (95% CI = 47.2–87.6%; 2015 September–2016 March) in 2015–2016. Monthly survival during December–February was 90.4% (95% CI = 85.3–93.9%), whereas survival during remaining months was 99.4% (95% CI = 97.7–99.9%). Human-caused mortality was most common (*n* = 10), followed by infection (*n* = 2), and interaction with other bobcats (*n* = 2). Harvest rates were 28.6% (8.2–64.1%; 95% CI), 14.3 % (5.7–31.5%; 95% CI), and 8.8% (3.0–23.0%; 95% CI) for 2013, 2014, and 2015, respectively. Population estimates for 2013, 2014, and 2015 were calculated using bobcats ≥1 year of age; population size for western South Dakota (excluding Black Hills) for 2013–2015 was 450 (113–788, 95% CI), 839 (279–1400, 95% CI), and 1315 (296–

2329, 95% CI), respectively. Overall 95% fixed kernel home range for adult females and males averaged 23.4 km^2 (SE = 4.9) and 80.0 km^2 (SE = 12.2), respectively. Additionally, juvenile bobcat 95% fixed kernel home range averaged 72.3 km^2 (SE = 18.9). Male home range size was statistically larger than females ($P < 0.001$). Bobcats that produced a litter averaged 2.7 kittens/female. We noted a significant difference between the average number of placental scars by year ($P < 0.001$); mean number of placental scars for the 2012–2013 harvest season was statistically higher ($P < 0.001$;) than the 2013–2014 harvest season. The highest documented statewide pregnancy rate during the project occurred in 2014 (59.4%), whereas the lowest occurred in 2013 (46.9%). There was a difference ($P < 0.001$) among means in the Kidney Fat Index over the 3-year study; the 2014-2015 harvest season produced the lowest Kidney Fat Index compared to the 2012-2013 ($P < 0.001$) and 2013–2014 ($P = 0.006$) harvest seasons. Annually, lagomorphs comprised the largest percent frequency of stomach contents, except for lands east of the Missouri River during the 2014–2015 harvest season (small mammal and ungulate). Our confidence intervals overlap for our population estimates potentially indicating no annual increase in bobcat numbers; however, observed high survival rates and increasing reproductive output suggest the population has the potential to increase in our study area.

CHAPTER 1: GENERAL INTRODUCTION

Bobcats (*Lynx rufus*) have been present in North America for nearly 2 million years (Sunquist et al. 2014). They are the most widely distributed native feline in North America (Anderson and Lovallo 2003; Hansen 2007) occupying parts of southern Canada to central Mexico and from California to Maine (Hansen 2007). Adult bobcats vary in size, with males averaging 9.6 (6.4–18.3) kg and females averaging 6.8 (4.1–15.3) kg (Anderson and Lovallo 2003). Bobcats are ambush predators, capable of killing an adult ungulate (Jacques and Jenks 2008). Diet of the species varies throughout its range; lagomorphs constitute a large portion of their diet, along with rodents and upland game birds (Higgins et al. 2002; Anderson and Lovallo 2003). Female bobcats become sexually mature at 1 year, but do not significantly play a role in population recruitment until the second year of life (Crowe 1975). Gestation is approximately 63–70 days (Anderson and Lovallo 2003), with litters of 1–6 kittens that are weaned at 7–8 weeks (Hansen 2007). Juvenile bobcats disperse between 9 months–2 years of age, depending on the speed at which they master hunting skills (Hansen 2007). Males typically disperse farther than females, likely because they are seeking suitable home ranges and mates; 20–40 km are common dispersal distances (Hansen 2007), with 182 km being the longest recorded dispersal (Knick 1990).

Historically, bobcats were of little economic importance, with pelts averaging $5.00 USD during 1950–1970 (Hansen 2007). Bobcats rarely attacked domesticated livestock, which resulted in little incentive for state or federal agencies to focus management on the species (Anderson and Lovallo 2003). The passage of the Endangered Species Act (ESA) in 1973 and the Convention on International Trade in

Endangered Species of Wild Fauna and Flora (CITES) in 1975, prohibited the import of fur of endangered cats (Hansen 2007). Bobcats were listed under Appendix II of the CITES Treaty, indicating that the species was not endangered, but may become so unless trade was closely controlled (CITES 2015). Yearly harvest increased eightfold, from 1970 to 1977, and the average pelt price rose from less than $10.00 to $70.00 (Hansen 2007). Wildlife managers needed to understand current population dynamics and population status to manage the bobcat during a time of increased exploitation.

Bobcats were not a regulated furbearer in South Dakota, prior to 1975. From 1975–1977 bobcats were harvestable statewide during a defined season, whereas from the 1977–1978 season to the 2011–2012, harvest was allowed only on land west of the Missouri River (Broecher 2012). In 2012, a select number of counties east of the Missouri River were opened for bobcat harvest. Currently, South Dakota Department of Game, Fish and Parks (SD GFP) manages bobcat populations with an annual hunting and trapping season. Bobcats harvested in South Dakota are required to be checked and tagged by SD GFP personal allowing a census of all bobcats harvested annually. Since the implementation of the bobcat season, the number of bobcats harvested have varied (i.e., 62–934 animals) as has as season length (30–114 days, [Broecher 2012]). SD GFP collects age structure, sex ratio, and harvest data annually to monitor and assess population status of bobcats.

An array of information has been collected over the past 40 years to better manage the species. The first research project on bobcats occurred from 1978–1980, when Nomsen (1982) collected carcasses of harvested bobcats to assess placental scar counts and food habits of the species in western South Dakota. Fredrickson and Mack

(1994) addressed home range size, habitat use, and survival of bobcats along the Bad River in west-central South Dakota. The most recent study collected data from three study areas in South Dakota; objectives focused on food habits, habitat selection, survival, and population estimation (Mosby 2011). Bobcat population dynamics and status change temporally in response to cyclic prey populations and habitat modifications. Current data are essential to understanding and managing bobcats in South Dakota. Therefore, our objectives were to: 1) estimate a population in the western prairie region of South Dakota; 2) estimate survival, harvest rate, and causes of mortality; 3) estimate home range size; 4) estimate reproductive status; and 5) build a population model.

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CHAPTER 2: POPULATION DYNAMICS OF BOBCATS IN WEST-CENTRAL SOUTH DAKOTA

ABSTRACT - Management of bobcats (*Lynx rufus*) in South Dakota is based annual harvest numbers and biological data (age and sex) collected from harvested carcasses; however, little is known about survival and cause-specific mortality. Previous research had indicated that survival is variable throughout South Dakota; the Badlands regions had the lowest survivorship (0.43%) followed by Bon Homme (0.49%) and the highest recorded survival occurred in the Black Hills (0.76%). From 2012 to 2015 we radio-collared 51 (24 male, 27 female) bobcats ≥1 year of age in west-central South Dakota. We estimated survival and harvest rates and documented cause-specific mortality. Population size was estimated for our study area using annual harvest data and mark-recapture analysis of radio-collared bobcats. Our population estimates for our study area were extrapolated to estimate a bobcat population existing on land west of the Missouri River (excluding Black Hills). Overall annual survival rate was 74.2 (95% CI, 59.2–85.0; 2012–2015). We recorded 16 mortalities; 9 harvest, 6 natural causes and 1 incidental. Estimated harvest rates were 28.6% (2013–2014), 14.3% (2014–2015) and 8.8% (2015–2016). Population estimates for bobcats ≥ 1 year of age occupying our study area for 2013, 2014, and 2015 were 90 (22–157; 95% CI), 167 (56–279; 95% CI), and 262 (59–464, 95% CI), respectively. Density estimates for bobcats ≥1 year of age in 2013 was 1.57 bobcats/100 km^2, in 2014 was 1.67 bobcats/100 km^2, and in 2015 was 1.80 bobcats/100km^2. Our results indicate that the high survival rate and low harvest rate were comparable to other stable bobcat populations found in North America.

Key words: bobcats, South Dakota, population dynamics, cause-specific mortality

INTRODUCTION

Studies on bobcat (*Lynx rufus*) populations throughout North America rarely produce accurate or precise estimates due to small sample sizes and because the overall secretive nature of the animal make it difficult to study. Researchers have implemented an array of techniques to estimate densities of bobcats, including fecal transects (Ruell et al. 2009), scent-stations (Conner et al. 1983), radio-collaring, remote cameras (Larccucea et al. 2007), and ear-tagging. Radiotelemetry is likely the best method to assess survival, but is expensive and time consuming, and generally applies to a relatively small study area (Anderson and Lovallo 2003).

Information on population dynamics needed to improve understanding and enhance management of wildlife populations. Survival rates, recruitment, sex ratios, and causes of mortality are parameters that can influence viability in bobcat populations. Legal harvest has been documented as the major cause of annual mortality in exploited populations (Chamberlain et al. 1999; Rolley 1985); whereas in an unexploited population, human mortality caused by motorized vehicles was highest (Nielsen and Woolf 2002). Knick (1990) conducted computer simulations on a bobcat population in southeast Idaho and concluded that a harvest rate >20% can negatively impact populations. Mosby (2011) documented low survivorship and a high rate of exploitation, with 1 of 4 female bobcats surviving, in the Badlands region of South Dakota. Quantifying survival rates and sources of mortality can provide data to understand site-specific factors affecting bobcat populations.

Bobcats are economically and ecologically important furbearer in South Dakota. With an average monetary value of bobcat pelts being higher than other furbearers in South Dakota, it has been a concern of managers and the public to ensure a sustainable population of the species. In 1975, South Dakota Department of Game, Fish and Parks (SD GFP) implemented a hunting/trapping season that encompassed the entire state; in 1977–1978, the harvest season was restricted to lands located west of the Missouri River (Broecher 2012). SD GFP manages bobcat populations using annual harvest records and biological data (age and sex) collected from carcasses. Harvest numbers and season length have fluctuated temporally. The 1990–1991 season returned the fewest number of bobcats, (62), whereas the most reported bobcats harvested, (934), occurred in the 2006–2007 season (Broecher 2012). Following the 2011–2012 harvest season, bobcat harvest decreased annually through the 2014–2015 season, which was a 17-year low and raised concerns about the status of the population (Broecher 2012).

Current population dynamics are needed to address factors affecting the bobcat population and to accurately model the population, therefore our objectives were to 1) estimate annual survival rates for bobcats, 2) identify cause-specific mortality, and 3) estimate population size of bobcats in the western prairie region of South Dakota.

STUDY AREA

Our study area encompassed approximately 20,402 km^2 in west central, South Dakota west of the Missouri River (Fig. 1) and focused on prairie habitat within Pennington, Meade, Butte, and Perkins counties, which reported higher than average bobcat trapping season returns during 2003-2011 (Broecher 2012). Elevation ranged from 575-1343 m above mean sea level (USDA GeoSpatialDataGateway 2014). Average annual precipitation was 40 cm and mean temperatures ranged from -12° C in January to 30° C in July (National Oceanic and Atmospheric Administration [NOAA] 2015). Climate values were derived from data collected at the Newell, South Dakota weather station from 1981-2010 (NOAA 2015). The majority of land cover was dominated by graminoids and herbaceous species (78.5%), followed by cultivated crops (7.5%), shrub/scrub (4.1%), and hay/pasture (3.9%; USDA GeoSpatialDataGateway 2014). Grass species included smooth brome (*Bromus inermus*), western wheatgrass (*Pascopyrum smithii*), and buffalograss (*Bouteloua dactyloides*). Big sagebrush (*Artemisia tridentata*) was found in greater abundance in the western regions of the study area, whereas snowberry (*Symphoricarpos albus*) was found in the eastern portion. Agricultural land was planted to sunflowers (*Helianthus annus*) and wheat (*Triticum aestivum*). Cottonwoods (*Populus deltoides*) were found in riparian areas along the Cheyenne and Belle Fourche rivers and a hybrid of Rocky Mountain Juniper (*Juniperus scopulorum*) and Eastern red cedar (*Juniperus virginiana*) dominated the draws leading to riparian areas (Van Haverbeke 1968, Ode 1990).

The bobcat harvest season west of the Missouri River occurred from 15 December – 15 February in the 2012–2013 season, whereas later seasons (2013–2015) opened on 25 December and closed 15 February.

METHODS

Bobcat Capture and Data Collection

We captured bobcats from August 2012 to December 2015 using # 3 off-set, laminated Bridger foot-hold traps (Minnesota Trapline Products, Pennock, MN, USA). We used two different styles of cage traps, Homesteader Deluxe 42D (TruCatch, Belle Fourche, SD, USA) and a home constructed trap with a guillotine style door (109 cm L: 38 cm W: 53 cm H; FSL Enterprises, Pringle, SD, USA). We used an assortment of professionally produced feline-specific lures at foot-hold sets, including Milligan's Cat-Man-Do, Dobbin's Purrrfect, and O'Gorman's Powder River Cat Call (Minnesota Trapline Products, Pennock, MN, USA and Fur Harvester's Trading Post, Alpena, MI, USA); cage traps were baited with vehicle killed white-tailed deer (*Odocoileus virginianus*), cottontail rabbits (*Sylvilagus floridanus*), ring-necked pheasants (*Phasianus colchicus*), and sharp-tailed grouse (*Typmpanuchus phasianellus*) in combination with lures. We set traps along major drainages including: Belle Fourche River, Cheyenne River, Sulfur Creek, and Moreau River and selected trap locations based on bobcat sign (tracks and/or feces), photos obtained from trail cameras (Bushnell Outdoor Products, Overland Park, KS, USA), and sightings from landowners. We checked traps daily at sunrise to minimize stress and potential injuries to captured animals.

We hand-injected captured bobcats intramuscularly with 10 mg/kg Ketamine and 1.5 mg/kg Xylazine (Kreeger and Arnemo 2007); anesthesia was reversed with 0.125 mg/kg Yohimbine. Bobcats captured with foot-hold traps or those sustaining an abrasion received a subcutaneous injection of Penicillin (Apsen Veterinary Resources, Ltd., Liberty, MO, USA) at a rate of approximately 1cc per 13.5 kg of body weight. Each individual was weighed with a hanging spring scale (capacity 38 kg). We identified sex, aged bobcats as juveniles (approximately 6–18 months old) or adults by reproductive condition (Johnson et al. 2010), or by weight (Crowe 1975a), and collected biological data (blood, and body and teeth measurements) from all captured bobcats. All juvenile and adult bobcats > 5 kg were fitted with Very High Frequency (VHF; Model M2220B; 148–149 MHz) radio collars (Advanced Telemetry Systems, Isanti, MN, USA). Bobcats < 5 kg were not collared, but were marked with two numbered metal ear tags. We attempted to locate bobcats weekly using a fixed-wing aircraft equipped with an H-Type hand-held directional antenna (Advanced Telemetry Systems, Isanti, MN, USA), but certain conditions (e.g., weather, pilot availability) limited our flights to about once every 2 weeks. Our animal handling procedures followed guidelines recommended by the American Society of Mammalogists (Sikes et al. 2011) and were approved by the Institutional Animal Care and Use Committee at South Dakota State University (Approval no. 12-050A).

Data Analysis

We converted locations from radio-tracking surveys to monthly encounter histories (White and Burnham 1999), and censored individuals if we were unable to monitor in a given month and right-censored individuals when transmitters failed to transmit or fell off the animal. Collared bobcats < 1 year of age were excluded from analyses. Bobcat mortalities were assigned to the month we collected the carcass; if mortality date was uncertain, we used the mean date between the last known live signal and the date of the mortality signal. Bobcats harvested during a season with unknown harvest dates were assigned a mortality date; we used the mean date between last known live signal and the end of bobcat harvest season. We used a known fate model in Program MARK (White and Burnham 1999) to estimate survival and determine factors that influence survival. We developed 7, *a priori*, models (Table 1.) to investigate bobcat survival; variables selected included: year, sex, and age at capture. Also, we included two time-specific models to analyze effects of season (harvest [Dec-Feb vs remainder of the year] and breeding-gestation [Nov–May] vs parturition-lactation [June–Oct]). The encounter histories began in September and ended in August of the next year. We estimated yearly survival from 2012-2015 using 12–month encounter histories, whereas 2015–2016 survival rate was calculated using a 7–month encounter history. Similarly, monthly survival estimates for December–February where based on data collected from 2012–2016, whereas monthly survival for the remainder of year was based on data collected from 2012–2015.

Population size was determined using a mark-recapture analysis. Our “marks” were the number of active collars in our study area and “recaptures” were the number of collars returned from harvested bobcats. We estimated population size using a Lincoln-Petersen model with a Chapman modifier (Lancia et al. 2005), using harvested bobcats ≥1 year of age in our study area coinciding with the 2013–2014, 2014–2015 and 2015–2016 trapping seasons. We summed the number of harvested bobcats from field forms for each county in the study and then multiplied by the percent of the county (i.e., Pennington 33.7%, Perkins 53.0%) incorporated in our study area to calculated the number of bobcats harvested, assuming harvest pressure was constant throughout the counties. We calculated percent kitten composition from lands west of the Missouri River from 2014–2015; we used that percentage to remove kittens from the 2015–2016 bobcat harvest numbers for our population estimate. We used our population estimates to extrapolate an annual population estimate for the prairie landscape west of the Missouri

River, South Dakota. We calculated the area of the prairie landscape (102,471.07 km^2) and divided it by our study area (20,402 km^2); the result (5.02) was multiplied by our annual population estimate. The Lincoln-Peterson model is based on the following 3 assumptions: 1) the population is closed; 2) all animals are equally likely to be captured; and 3) marks are not lost, gained, or overlooked (Lancia et al. 2005). We assumed immigration was equal to emigration. To meet all three assumptions of the Lincoln-Petersen model we located radio-collared bobcats during the harvest season to validate they were present in the study area, we assumed a closed population, and we used the number of bobcats available on the first day of bobcat season for our estimates.

We used a composite home range method to estimate annual bobcat (≥1 year of age) densities in our study area. We used a Fixed-Kernel Estimator with Least-Squares Cross Validation (Worton 1989, Seaman and Powell 1996, Powell 2000) within the 'adehabitatHR' (Calenge 2011) package in Program R (R Core Team 2014) to estimate a 99% home range of each collared bobcat, annually. We then converted home ranges into shapefiles and mapped them in ArcGIS 10.2.2 (Environmental Systems Research Institute, Redlands, CA, USA) to evaluate composite 99% home range size. Individual home range polygons were dissolved to ensure no overlap. Density was calculated by dividing the number of home ranges used for the analysis by the area (km^2) of the composite home range and multiplied by 100 to predict the number of bobcats/100 km^2.

We calculated harvest rates using the number of bobcats harvested throughout each season divided by the number of bobcats available on the first day of the season. We assumed constant trapper effort while calculating harvest rates. We did not include bobcats captured and collared during the hunting/trapping season.

Population Model

We used Microsoft Excel to model population size (Table 2.) of bobcats using current population dynamics and referenced variables not included in our study. Derived parameters we estimated were based on bobcats ≥1 year of age. We obtained harvest numbers from SD GFP and included harvested bobcats from lands west of the Missouri River (excluding the Black Hills). We subtracted the bobcats harvested from the western South Dakota (excluding the Black Hills) population from the estimated population size to ascertain the number of bobcats remaining after bobcat harvest season. The mean sex ratio from harvested bobcats was approximately 1 male/female; however, the sex ratio for our study was 0.9 male/female. Sex ratios that come from harvest data may not represent actual sex ratio, but may reflect relative trapping vulnerability during the breeding season (Anderson and Lovallo 2003). Therefore, we used the sex ratio from our study to offset potential male based vulnerability during bobcat harvest season. We multiplied the number of bobcats remaining after harvest by sex compostion to obtain the number males and females available after harvest. Reproduction rate was calculated annually from mean placental scars of harvested female bobcats in western South Dakota (excluding the Black Hills). The 2015 reproduction rate was the mean of 2012–2014 placental scar counts. We derived kittens produced by multiplying females remaining and the reproduction rate. Crowe (1975b) used life tables to estimate kitten survival in Wyoming and it fluctuated from 18–71%. Kitten survival was 30% in Oklahoma (Rolley 1985) whereas, in Maine Litvaitis et al. (1987) reported 40% survival kitten and 71% adult survival. We used a 40% survival for kittens because literature gathered that presented both adult survival and kitten survival with similar adult survival came from Maine

(Litvaitis et al. 1987). Kittens surviving to the first harvest season was calculated by multiplying kittens produced and kitten survival rate. We added males and females remaining after the harvest to obtain an adult bobcat total. Survival rate from March–November was derived from our top survival model. We multiplied adults and survival rate to obtain an estimate of adults available at day one of the harvest season. The total was calculated by adding kittens surviving and adults alive at harvest. We added kittens surviving and adults alive at harvest to derive a total estimate of bobcats available on day one of harvest season the following year.

Results

From September 2012 to December 2015, we captured and radio-collared 51 bobcats (24 male, 27 female). Of the 51 captured bobcats, two (1 male, 1 female) were not included in survival analyses; one bobcat was euthanized due to a broken leg and another was put down because it was hypothermic. We captured three bobcat kittens (1 male, 2 female) during the study that received ear tags. One kitten was reported dead, but the carcass was missing when we went to investigate the mortality.

We used 19 encounter histories in 2013–2014, 35 encounter histories in 2014–2015, and 36 encounter histories in 2015–2016 to estimate annual survival. Our top ranked model {S(harvest)} carried most of the AIC_c weight (0.93) and was >5 ΔAIC_c lower than the next model (Table 3). Monthly survival during December–February was 90.4% (95% CI = 85.3–93.9%; 2012–2015), whereas survival during remaining months was 99.4% (95% CI = 97.7–99.9%; 2012–2014). Estimated annual survival was 65.1% (95% CI = 35.9–86.2%) in 2013–2014, 75.9% (95% CI = 57.4–88.0%) in 2014–2015, and 71.5 % (95% CI = 47.2–87.6%) in 2015–2016 (September 2015–March 2016). The survival for the 36-month duration of the study was 74.2% (95% CI = 59.2–85.0%; 2012–2014).

We documented a total of 16 mortalities (Table 4) from 2013–2016. The majority of mortalities (56.3%) were from legal harvest (9; 6 male, 3 female). In the 2013–2014 trapping season, two (1 male, 1 female) radio-collared bobcats were harvested, four (2 male, 2 female) were harvested in the 2014–2015 season, and three (3 male) were harvested in the 2015–2016 season. Other causes of mortality included: infection (12.5%), interaction (12.5%), starvation (6.3%), incidental harvest (6.3%), and unknown causes (6.3%). The two bobcats that were classified as dying from infection had lacerations that penetrated into the muscle tissue and caused internal damage that led to infected organs. In 2014, a female juvenile bobcat carcass was located with large bobcat tracks surrounding the carcass and upon further necropsy had puncture marks in the skull, which suggested the bobcat was killed by another adult bobcat. We collected an adult male bobcat carcass in 2015 with bruising and puncture marks around head and neck with no flesh consumed and classified the mortality as interaction. Porcupine (*Erethizon dorsaum*) quills were found imbedded in the mouth and paws of a large male bobcat, which led to its starvation. Remains of a female bobcat were collected, but were deteriorated, and thus the cause of death was unknown. After the 2015–2016 bobcat harvest season, a radio-collared bobcat was incidentally snared and killed.

During the 2013–2014 hunting/trapping season a total of seven (1 male, 6 female) radio-marked bobcats were available for harvest; 34 bobcats (≥1 year of age) were harvested in the study area, and two (1 male, 1 female) were radio-marked (Table 5).

During the 2014–2015 hunting/trapping season 28 (12 male, 16 female) radio-marked bobcats were available for harvest, and 24 bobcats (≥ 1 year of age) were harvested in the study area, of which four (2 male, 2 female) were radio-marked. During the 2015–2016 hunting/trapping season 33 (16 male, 17 female) radio-marked bobcats were available for harvest; 29 bobcats (≥1 year of age) were harvested in the study area, and three (3 male) were radio-marked. Population estimates for bobcats ≥1 year of age in 2013, 2014, and 2015 were 90 (22–157; 95% CI), 167 (56–279; 95% CI), and 262 (59–464, 95% CI), respectively (Table 6). Population estimates of bobcats ≥1 year of age for lands west of the Missouri River (excluding Black Hills), South Dakota for 2013, 2014, and 2015 were 450 (113–788, 95% CI), 839 (279–1400, 95% CI), and 1315 (296–2329, 95% CI), respectively. Harvest rate for the 2013–2014 season was 28.6% (8.2–64.1%; 95% CI), 14.3 % (5.7–31.5%; 95% CI) for the 2014–2015 season, and 8.8% (3.0–23.0%; 95% CI) for the 2015–2016 season. Estimated densities were 1.57 bobcats/100 km^2 in 2013, 1.67 bobcats/100 km^2 in 2014, and 1.80 bobcats/100 km^2 in 2015.

The population model (Table 2.) we created tracked population size below the mark-recapture population estimates, but produced estimates within our confidence intervals. The margins between the mark-recapture and model predicted estimates narrowed over time.

Discussion

Population characteristics of bobcats were previously studied in South Dakota and our study provides new data to understand bobcat ecology and the influence of management in the region. Mosby (2011) documented survival in three study areas across South Dakota and found survival rates varied from 43–76% (Mosby 2011). Our overall estimated survival rate was similar to the upper limit of survival from the aforementioned project, which was documented in the Black Hills. Unexploited bobcat populations generally have higher survival (0.87–0.95; [Nielson and Woolf 2002]), although Mosby (2011) documented a survival rate of 0.49 in southeastern South Dakota. Exploited populations have a tendency for lower survival due to human-related factors (e.g., hunting and trapping). However, in unmanipulated mountain lion populations other human-related mortality factors (e.g., vehicle collisions and lethal removals) can reduce populations significantly (Thompson et al. 2014). Our study area included four counties in South Dakota that reported some of the highest harvest of bobcats in South Dakota. Despite our harvest rates, our annual survival estimate was higher when compared to the Badlands of South Dakota (0.43 [Mosby 2011]), Oklahoma (0.56 [Rolley 1985]), Massachusetts (0.62 [Fuller et al. 1995]), and two study sites in north-central Minnesota (0.19 and 0.61 [Fuller et al. 1985]). We modeled our survivorship across 3 years with 12-month intervals. Survivorship in 2015–2016 was based a 7–month encounter history; survival rate may be biased low due to the number of bobcat not found during flights. Our top model, S{harvest}, indicated survival was less in December–February compared to the remainder of the year; the December–February period corresponded with the bobcat harvest season. However, harvest was not the sole cause of mortality in those three months (3 out of 6 non-harvest mortalities occurred in December–February), natural causes also affected bobcat survival.

All bobcats we captured during this project were on private property, except for one individual captured in a road right-of-way. Radio-collared bobcats spent most of their time on private lands or on public lands surrounded by private lands which may have biased our estimates high. During the project, approximately 35% of the ranches did not allow bobcat trapping on their property, or after allowing capture of bobcats on their property ranchers ceased all bobcat trapping on their lands. Bobcats did not exclusively remain on these "protected" lands, but they may have spent a majority of time there during the harvest season. For example, we documented movements across road right-of-way to other properties that allowed bobcat harvest. In addition, we documented a bobcat that remained on private land closed to trapping for the duration of the study.

Harvest was our main source of mortality during the study, which was consistent with other exploited bobcat populations in North America. Trapper/hunter-caused mortality was 62.0%, which was greater than documented by Mosby (2011; 37.5%). States such as Idaho (Knick 1990) and Maine (Litvaitis et al. 1987) had similar mortality rates via harvest. The other 38.0% of mortality in our study was not due to human interaction. Radio collars that switched to mortality signal were located the next day and deaths were attributed to natural factors (i.e., infection, interaction with another bobcat, and starvation). An unknown cause of mortality (female) of a bobcat occurred in May and thus, could be linked to complications associated with parturition or stressors related to rearing of young (e.g., lactation). Data collected on bobcats in central Mississippi supported this hypothesis regarding lower survivorship among females with young during the parturition-young rearing stage (Chamberlain 1999). Illegal harvest was non-existent in our study area, which was similar to findings of Mosby (2011); however, studies in Missouri (Hamilton 1982), Minnesota (Fuller et al. 1985), and east of the Missouri River in South Dakota (Mosby 2011) reported rates of illegal harvest of 58%, 41%, and 20%, respectively. Although we found no evidence of vehicle-killed bobcats, we did have two reported incidences of animals being struck by vehicles in our study area (personal communications).

The 2013–2014 trapping season recorded a high harvest rate (28.6%), but this may be biased high due to a low sample size (n = 7). Caution is advised with this estimate however, the highest monetary value occurred in 2013 when pelt prices averaged $589.08 USD (NAFA 2016) potentially influencing harvest pressure. A model simulation based on a bobcat population in southeast Idaho indicated that the population decreased when the harvest rate surpassed 20% (Knick 1990). With a larger sample size of radio-collared bobcats in the 2014–2015 and 2015-2016 trapping seasons our estimate of harvest rate was below the 20% threshold (e.g., 14.3% and 8.8%). Nevertheless, our sample size of bobcats residing on private land could have affected the precision of our harvest rate estimate due to the fact that some bobcats remained mostly on private land where trapping pressure was likely reduced compared to adjacent properties.

Trapping effort can be linked to pelt prices and if not adjusted can skew estimates of harvest rates. Trappers interviewed in New York reported that pelt prices are an important factor influencing their decisions to trap annually (Siemer et al. 1994). Increased value in pelts has resulted in increased harvest in Oklahoma (Rolley 1985). We did not survey bobcat trappers in South Dakota to validate the influence of pelt prices and trapping effort. We did observe a declining trend in pelt prices (NAFA 2016) along with a decline in harvest rates. Although we did not verify a direct link to pelt prices and harvest rates, we hypothesize bobcat fur prices influence trapper effort and therefore harvest rates.

Our density estimates were similar over the duration of the project, slightly increasing annually. In the 2013–2014 and 2014–2015 harvest season, no bobcats <1 year of age were radio-collared; therefore, our population and density estimates were calculated using ≥1 year of age bobcats. During the 2015–2016 harvest season, we had <1 year of age bobcats radio-collared (*n* = 2). The proportion of <1 year of age bobcats in the harvest is approximately 20% (SD GFP, unpublished data), whereas the proportion radio-collared in 2015–2016 was 6%. The proportion of bobcats <1 year of age radio-collared may not represent that actual proportion in the population, which bias our estimates. Therefore, bobcats <1 year of age were not included in analyses. Our density estimates were relatively low compared to other states including Oklahoma (9.00/100km^2; Rolley 1985), Illinois (34.0/100km^2; Nielson and Woolf 2001), and northwest Wisconsin (6.90/100km^2; Lovallo and Anderson 1996). We estimated density from known bobcat habitat. The relatively low density estimates were influenced by not including kittens in any of the estimates.

Statewide bobcat harvest has decreased annually from 2012 to 2015. Our study area produced approximately 16% (12–19%) of South Dakota's annual harvest. Previous research documented variable survivorship across different ecotypes in South Dakota (Mosby 2011); therefore, management decisions should be made based on region specific objectives. We recommend using caution if extrapolating results from our study to other regions of South Dakota because of large confidence intervals observed in our estimates. Over the past three harvest seasons, the number of harvested bobcats has decreased in

South Dakota. Survival and harvest rate estimates, however, were comparable to other states that have stable bobcat populations. Through the 1978–1980 period when South Dakota held bobcat harvest seasons, Nomsen (1982) calculated a mean litter size of 2.7; the mean litter size for bobcats during our study was 2.7, however, pregnancy rates varied in western South Dakota (*see* Chapter 4). A decline in pregnancy rates directly affects recruitment into the population; poor recruitment over time may account for the declining population. Estimates of bobcat survival and population density will allow managers to make management decisions based on sound scientific research. Future studies should focus on kitten survival to document variables influencing recruitment and other ecological factors influencing survival.

Population modeling can be used as a management tool to predict the trajectory of a species abundance from population dynamics obtained from the specified species. Managers must understand how rates of survival, fecundity, immigration, and emigration influence the persistence of a species population to project a carnivore population (Gese 2001). We observed a bobcat who established a home range on the northern boundary of the study area that would periodically leave, but would return and be available for harvest within study area. The locational data we collected did not support significant emigration from the study area and therefore, we assumed immigration and emigration was equal for analysis purposes. State and Federal agencies have used population models to estimate numbers of moose (Messier 1994), passerine birds (Noon and Sauer 1992), and mountain lions (Beier 1996). Complex models of population dynamics may capture most of our knowledge of the of the specified species, but may be limited to because of the lack of annual information on required inputs (White 2000). Therefore, we constructed our population model to enable managers the ability to incorporate annual reproductive output and harvest numbers. The ability to forecast future population size is an essential factor in management practices, especially in a carnivore species with annual variation in population parameters and our model can be modified to ensure that model results are supported by empirical data.

Management Implications

Our estimated survival and harvest rates throughout the study were comparable to stable populations. Although we documented a decline in bobcats harvested annually in western South Dakota, our annual population estimates were similar with overlapping confidence interval among all three years. The decline in pelt prices may be correlated with the annual decline in harvest based on the trend we observed during the study. The increase of lagomorphs during a time of low pelt prices may allow the bobcat population to grow with a decline in harvest pressure. Cyclic prey species, like lagomorphs, may affect bobcat population parameters and increase intraspecific competition among the species in years of low prey densities. Years of high prey densities bobcats may tolerate transients within their home range. However, we documented two fatal interactions between bobcats indicating aggressive behavior among bobcats defending limited resources.

Caution is advised with extrapolation population estimates; different habitat and population dynamics present in South Dakota may have different bobcat densities than our study area. Our population model produced estimates lower than the mark-recapture estimates, but these estimates were within our 95% confidence intervals. Additionally, the population model can be updated annually with new harvest data to predict the most current bobcat population. It is important to note 13 of 16 mortalities occurred from December–February and 15 of 16 occurred from November-February. Indicating bobcats are most susceptible to natural and human-caused mortality during the winter months.

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Figure 1. Study area in which bobcats were captured, located in west-central South Dakota, which include Butte, Meade, Pennington, and Perkins counties, South Dakota.

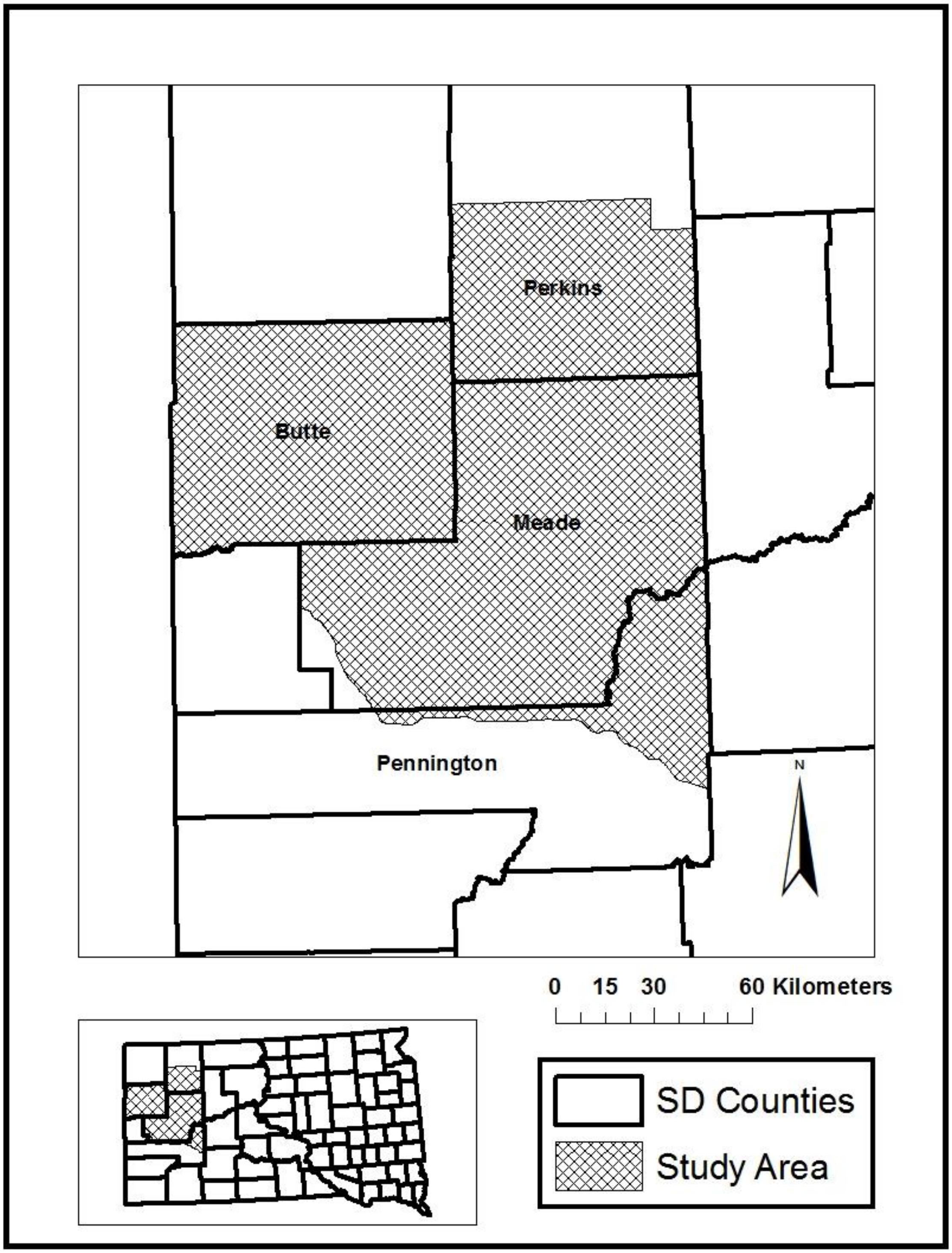

Table 1. Models constructed, *a priori*, to evaluate influences on annual survival of bobcats in west-central South Dakota, USA, 2013-2015.

Model	K	Description
{S(time)}	12	Survival Varied by Month
{S(harvest)}	2	Survival Differed from Harvest Season (Dec-Feb)
{S(nov-may)}	2	Survival Differed from Breeding (Nov-May) vs Parturition(June-Oct)
{S(.)}	1	Survival was constant
{S(year)}	2	Survival Differed by Year
{S(sex)}	2	Survival Differed by Sex
{S(age)}	2	Survival Differed by Age (juvenile vs adult)

Table 2. Modeled population derived from harvest and population dynamics of bobcats from western South Dakota, USA, 2012–2015.

Year	Mark-Recap Estimate	Model Predicted Population	Harvested WR (≥1)	Remaining Population
2013	450	N/A	185	265
2014	839	351	145	694
2015	1315	936	113	1202
2016		1548		

Year	Male Comp	Female Comp	Males after harvest	Females after harvest
2013	0.47	0.53	125	140
2014	0.47	0.53	326	368
2015	0.47	0.53	565	637
2016				

Year	Reproduction Rate	Kittens Produced	Kitten Survival Rate	Kittens Surviving
2013	1.05	250	0.4	100
2014	1.57	698	0.4	279
2015	1.47	1025	0.4	410
2016				

Year	Adult total (M+F)	Survival rate March-Nov	Adults alive at harvest	Total
2013	265	0.947	251	351
2014	694	0.947	657	936
2015	1202	0.947	1138	1548
2016				

Table 3. Model results for factors affecting bobcat survival in west-central South Dakota, USA.

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance
{S(harvest)}	90.98	0.00	0.93	1.00	2	86.96
{S(nov-may)}	96.40	5.41	0.06	0.07	2	92.37
{S(time)}	101.11	10.13	0.01	0.01	12	76.39
{S(.)}	105.24	14.26	0.00	0.00	1	103.23
{S(year)}	105.50	14.52	0.00	0.00	2	101.48
{S(sex)}	107.10	16.12	0.00	0.00	2	103.07
{S(age)}	107.22	16.24	0.00	0.00	2	103.20

[a] Model results based on data collected from September 2012–August 2015

Table 4. Cause-specific mortality of bobcats in west-central South Dakota, USA, 2013-2015.

Cause-specific mortality	*n*	**%**
Harvest	9	56.3%
Infection	2	12.5%
Interaction	2	12.5%
Starvation	1	6.3%
Incidental Harvest	1	6.3%
Unknown	1	6.3%

Table 5. Radio-marked bobcat availability and harvest data for bobcats in 2013-2014, 2014-2015, and 2015-2016 hunting/trapping seasons in west-central South Dakota.

	2013-2014	2014-2015	2015-2016
# Bobcats Available	7	28	34
# Marked Bobcats Harvested	2	4	3
Total Harvested	33	24	29

Table 6. Population estimates for bobcats aged ≥1 in 2013, 2014, and 2015. Estimates were calculated using a 2-sample Lincoln-Petersen estimator with a Chapman modification, using radio-marked bobcats from west-central South Dakota.

	2013	2014	2015
N	90	167	262
SE	34	57	103
Lower 95% CI	22	56	59
Upper 95% CI	157	279	464

CHAPTER 3: HOME RANGE CHARACTERISTICS OF BOBCATS IN WEST-CENTRAL SOUTH DAKOTA

ABRACT- Recent declines in harvested bobcats (*Lynx rufus*) piqued interest in obtaining information to aid in understanding the mechanisms causing population variation. From September 2012–December 2015 we radio-collared 54 (26m, 28f) bobcats ≥1 year of age in west-central South Dakota. We collected 1,271 ground and aerial locations on study animals to estimate home range size. Mean 95% fixed kernel home range estimate for adult females was 29.4 km^2 (SE =4.9, *n*=16), whereas mean 95% fixed kernel estimate for males was 80.0 km^2 (SE=12.2, *n*=10). In 2014 and 2015, the mean 95% fixed kernel estimates for adult females were 39.7 km^2 (SE=7.7, *n*=9) and 20.6 km^2 (SE=3.9, *n*=14), respectively; male mean 95% fixed kernel home range estimates were 91.4 km^2 (SE=2.4, *n*=2) and 83.1 km^2 (SE=15.7, *n*=9), respectively. The overall mean 95% fixed kernel home range estimate for juvenile bobcats was 72.3 km^2 (SE=18.9, *n*=10). Mean male home range size was larger than that of females ($P < 0.001$), but we found no difference ($P = 0.14$) of means in female home ranges between 2014 and 2015. These results indicate bobcats in west-central South Dakota require large home ranges to meet energy requirements, likely because of the expansive grasslands that characterize the region.

Key words: bobcats, South Dakota, fixed kernel, juveniles, home range

INTRODUCTION

Bobcats (*Lynx rufus*) are the most widely distributed native felid in North America (Anderson and Lovallo 2003). Bobcats are a solitary felid with social interactions being brief, with exceptions during the breeding season (Anderson and Lovallo 2003). Interest in spotted cats increased after the passing of the Convention on

International Trade in Endangered Species (CITES) Act of 1973, which made bobcats and lynx (*Lynx canadensis*) valuable commodities due to the illegality of harvesting endangered spotted cats in other countries (Hansen 2007). Thus, managers throughout North America were encouraged to increase understanding of bobcat populations within their management boundaries.

Home range size can help provide information regarding population dynamics and prey density. Burt (1943) defined home range as an area traversed by the individual in its normal activities of foraging, mating, and caring for young. Home ranges size of bobcats vary throughout their range; larger home ranges typically are found at northern latitudes and decrease in size in southern latitudes (Lawhead 1984, Litvaitis et al. 1986, Anderson and Lovallo 2003). There are four defined social classes in bobcat populations: adult male, adult female, kitten, and transient (Kamler and Gipson 2000). Males typically inhabit larger home ranges compared to females in all seasons, but home ranges tend to fluctuate during the summer and winter months as metabolic demands vary (Anderson and Lovallo 2003). Transient bobcats typically have large, less defined home ranges, whereas kittens tend to inhabit the smallest home ranges (Kamler and Gipson 2000). Modification of the landscape may influence home range size and consequently affect resource availability. For example, studies have documented an inverse relationship between home range size and prey densities (Ward and Krebs 1985, Knick 1990).

Interspecific home range overlap between females can be non-existent to slight, whereas males have been documented having significant overlap in home range; males have been known to encompass ≥1 female home range within their territories (Lawhead 1984), which increases breeding potential. As mortality occurs and resident bobcats are removed, transient bobcats have been known to fill the vacant home ranges (Litvaitis et al. 1987). Natal dispersal is defined as the movement of an individual from its site of origin to a new and separate breeding site (Gompper et al. 1998). Dispersal is a mechanism hypothesized to have evolved to minimize resource competition and reduce inbreeding (Janečka et al. 2007).

Advances in technology, especially in radio telemetry, have been beneficial in monitoring and collecting locational data on secretive, low density species, such as bobcats. Geographical information systems (GIS) have improved our ability to map home ranges and understand the functionality that habitat has on animal movements on the landscape. Several carnivore studies that focused on home range analyses utilized several different methods to quantify an area in which animals inhabit including minimum convex polygons (MCP [Nielson and Woolf 2001]), Adaptive-Kernel (Fecske 2003), Fixed-Kernel with Least-Squares Cross Validation (LSCV [Koehler 2006]), and Brownian Bridge Movement Models (BBMM [Mosby 2011, Wilckens 2014]). Early attempts at identifying home range revolved around the use of MCP (Kie et al. 2010); which is known for its simplicity, but has been shown to bias home range estimates (Burgman and Fox 2003). Kernel methods are becoming more widely used in the wildlife field for estimating home range size due to the advantage of nonparametric approaches and ability to produce low bias results (Worton 1989, Seaman and Powell 1996, Kie et al. 2010). The LSCV fixed kernel method uses the bandwidth that gives the lowest mean integrated square error for the density estimate (Seaman and Powell 1996), which can produce different smoothing parameters for each individual, thereby increasing accuracy of estimates.

Bobcats in South Dakota are a valuable furbearer that was exploited year-round and statewide until the first harvest season was implemented in 1975 (Broecher 2012). Records on season dates, length of season, and number of bobcats harvested have been collected since the initiation of the first season (Broecher 2012). Harvest records reported through time have varied since the first bobcat season. Habitat and habitat quality can change temporally based on rainfall and agricultural practices that may alter prey densities. Mosby (2011) documented large home ranges in the Badlands and the Black Hills region of South Dakota. Despite the information that has been collected on the species in South Dakota, bobcats have not been studied within the prairie landscape in the west-central region of the state.

Our objectives were to estimate 50% and 95% fixed kernel home ranges and document dispersal movements of bobcats. In addition, we compared results to information previously collected on the species in South Dakota (Mosby 2011). Knowledge gained from this study will help to understand functional response of bobcats to habitat quality and resource limitation to help improve management.

STUDY AREA

Our study area was located in the prairie region of South Dakota west of the Missouri River (Fig. 1). Our research focused on prairie habitat with higher than average harvest of bobcats which included the counties of Pennington, Meade, Butte, and Perkins; the area encompassed approximately 20,402 km^2 in west-central, South Dakota. We focused our efforts along major drainages including the Belle Fourche, Cheyenne, and Moreau rivers, and along Sulfur creek. Elevation of the area ranged from 575-1343 m above mean sea level (USDA GeoSpatialDataGateway 2014). Average annual precipitation was 40 cm; mean temperatures ranged from -12° C in January to 30° C in July (National Oceanic and Atmospheric Administration [NOAA] 2015). Climate data were derived from the Newell, South Dakota weather station from 1981-2010 (NOAA 2015). The majority of land cover was dominated by graminoids and herbaceous species (78.5%), with pockets of cultivated crops (7.5%), shrub/scrub (4.1%), and hay/pasture (3.9%; USDA GeoSpatialDataGateway 2014). Cottonwoods (*Populus deltoides*) are found in riparian areas along the Cheyenne and Belle Fourche rivers and a hybrid of Rocky Mountain Juniper (*Juniperus scopulorum*) and Eastern red cedar (*Juniperus virginiana*) dominated the draws leading to riparian areas (Van Haverbeke 1968, Ode 1990). Grass species included smooth brome (*Bromus inermus*), western wheatgrass (*Pascropyrum smithii*), and buffalograss (*Bouteloua dactyloides*). Big sagebrush (*Artemisia tridentata*) was found in greater abundance in the west, whereas snowberry (*Symphoricarpos* albus) was more common in the eastern portion of the study area. Commonly planted agricultural crops included sunflowers (*Helianthus annus*) and wheat (*Triticum aestivum*).

METHODS

Bobcat Capture and Data Collection

We captured bobcats from August 2012 to December 2015 using # 3 off-set, laminated Bridger foot-hold traps (Minnesota Trapline Products, Pennock, MN, USA). We also used two different styles of cage traps, Homesteader Deluxe 42D (TruCatch, Belle Fourche, SD, USA) and a home constructed trap with a guillotine style door (109 cm L: 38 cm W: 53 cm H; FSL Enterprises, Pringle, SD, USA). We used an assortment of professionally produced feline-specific lures at foot-hold sets, including Milligan's Cat-Man-Do, Dobbin's Purrrfect, and O'Gorman's Powder River Cat Call (Minnesota Trapline Products, Pennock, MN, USA and Fur Harvester's Trading Post, Alpena, MI, USA); cage traps were baited with vehicle killed white-tailed deer (*Odocoileus virginianus*), cottontail rabbits (*Sylvilagus floridanus*), ring-necked pheasants (*Phasianus colchicus*), and sharp-tailed grouse (*Typmpanuchus phasianellus*) in combination with lures. We selected trap locations based on bobcat sign (tracks and/or feces), photos obtained from trail cameras (Bushnell Outdoor Products, Overland Park, KS, USA), and sightings from landowners. We checked traps daily at sunrise to minimize stress and potential injuries to captured animals.

We hand-injected captured bobcats intramuscularly with 10 mg/kg Ketamine and 1.5 mg/kg Xylazine (Kreeger and Arnemo 2007); anesthesia was reversed with 0.125 mg/kg Yohimbine. Bobcats captured with foot-hold traps or those sustaining an abrasion received a subcutaneous injection of Penicillin (Apsen Veterinary Resources, Ltd., Liberty, MO, USA) at a rate of approximately 1 mg per 13.5 kg of body weight. Each individual was weighed with a hanging spring scale (capacity 38 kg). We identified sex, aged bobcats as juveniles or adults by reproductive condition (Johnson et al. 2010), or by weight (Crowe 1975), and collected biological data (blood, and body and teeth measurements) from all captured bobcats. All juvenile and adult bobcats above 5 kg were fitted with Very High Frequency (VHF; Model M2220B; 148–149 MHz) radio collars (Advanced Telemetry Systems, Isanti, MN, USA). Bobcats below 5 kg were not collared, but were marked with two numbered metal ear tags. We attempted to locate bobcats weekly using a fixed-wing aircraft equipped with an H-Type hand-held directional antenna (Advanced Telemetry Systems, Isanti, MN, USA), but certain conditions (e.g., weather, pilot availability) limited our flights to about once every 2 weeks. Out animal handling procedures followed guidelines recommended by the American Society of Mammalogists (Sikes et al. 2011) and were approved by the Institutional Animal Care and Use Committee at South Dakota State University (Approval no. 12-050A).

Data Analysis

We estimated home range size for juvenile bobcats, and added core area estimates for adults, using a Fixed-Kernel Estimator with Least-Squares Cross Validation (Worton 1989, Seaman and Powell 1996, Powell 2000) within the 'adehabitatHR' (Calenge 2011) package in Program R (R Core Team 2014). This method produces multiple polygons with the least amount of bias (Powell 2000) for each utilization distribution (UD). We then converted home ranges into shapefiles and mapped them in ArcGIS 10.2.2 (Environmental Systems Research Institute, Redlands, CA, USA) to evaluate home range size and shape. We used a 95% UD to estimate a home range size and a 50% UD for a core area. Sallies (i.e., occasional forays [Burt 1943]) were not considered part of home ranges (Burt 1943, Powell 2000, Calenge 2011). We then manually removed locations deemed "sallies" to reduce bias in UDs (Powell 2000) using ArcMap (Environmental Systems Research Institute, Redlands, CA, USA). Optimal bandwidth can be influenced by the spatial spread and pattern of observed locations (Millspaugh et al. 2012). Home range estimates with small sample sizes may be biased high using the Least-Squares Cross Validation (LSCV) function in adehabitatHR (Calenge 2011). Based on observations, we believe adult bobcats with established home ranges did not cross major waterways (e.g., Cheyenne and Belle Fourche Rivers); therefore, we bounded home ranges along rivers to reduce the chance of overestimating home range size.

At least 15 locations were used to estimate adult bobcat home ranges, whereas a minimum of 10 locations was used to estimate juvenile home ranges. Bobcats aged 6–18 months were considered juveniles and bobcats >18 months were classified as adults (Crowe 1975). Natal range locations were not included in the home range estimation for juvenile bobcats (Kamler and Gipson 2000). We used adult bobcat locations only to estimate home range size on an annual basis and combined locations collected throughout the study to calculate overall home range size. We used analysis of variance (ANOVA) to test for differences in home range size based on gender and a paired t-test to evaluate differences in annual home range size using Program R.

Results

We captured and radio-collared 51 (24 male, 27 female) bobcats from September 2012–December 2015. We captured 13 male and 18 female adult bobcats; average weight was 11.6 kg (SE = 0.5) and 9.1 kg (SE = 0.2), respectively. In addition, we captured 11 male and 7 female juvenile bobcats; average weight was 7.6 kg (SE = 0.5) and 5.8 kg (SE = 0.4), respectively. Total length for adult males averaged 103.3 cm (SE = 1.6), whereas adult females averaged 95.3 cm (SE = 0.8). Total length for juvenile male bobcats averaged 92.3 cm (SE = 2.9), whereas females averaged 84.6 cm (SE = 2.1).

We used a fixed wing aircraft to collect 1,271 locations from 41 individual bobcats. We calculated home ranges for 10 juvenile bobcats using 191 locations (range 11–26). In addition, we collected 834 locations from 10 males (range 18–49) and 16 females (range 20–68), which were used to map adult bobcat home ranges. In 2014, we collected 310 locations from two males (range 28–31) and nine females (range 19–37); in 2015, we collected 512 locations from nine males (range 18–24) and 14 females (range 19–25).

Overall 50% and 95% fixed kernel home ranges averaged 19.7 km^2 (SE=3.0) and 80.0 km^2 (SE=12.2), respectively, for males (Table 1). Fixed kernel home ranges (50 and 95%) for males in 2014 and 2015 averaged 22.5 km^2 (SE=2.4) and 91.4 km^2 (SE=2.4), and 21.4 km^2 (SE=4.5) and 83.1 km^2 (SE=15.7), respectively. We were unable to compare home range size for male bobcats between years due to small sample size; BC19 was the only adult male with sufficient locational data in both 2014 and 2015, but home range was approximately 45% larger in 2015 compared to 2014.

The overall 50% and 95% fixed kernel home ranges for female bobcats averaged 7.1 km^2 (SE=1.3) and 29.4 km^2 (SE=4.9), respectively. Annual fixed kernel female home ranges (50 and 95%) were 9.1 km^2 (SE=1.9) and 39.7 km^2 (SE=7.7) in 2014 and 4.9 km^2 (SE=1.1) and 20.6 km^2 (SE=3.9) in 2015, respectively. Between 2014 and 2015, 95% home range size for adult females did not differ (95%, F=2.35, df=1, P=0.14); however, 50% core area size did show a difference at the 94% confidence level (50%, F=3.90, df=1, P=0.06). Furthermore, adult females that were monitored in both 2014 and 2015 did not show a significant difference in average home range or core area size (t=1.96, df=6, P=0.10) and (t=1.82, df=6, P=0.12), respectively. However, there was a significant difference in mean home range and core area size between males and females (95%, $F=18.12$, $df=1$, $P < 0.001$) and (50%, $F=23.28$, $df=1$, $P<0.01$), respectively; home range and core area size of males was larger than for females.

Juvenile bobcat 95% fixed kernel home range averaged 72.3 km^2 (SE=18.9). We documented both males and female juveniles making extensive movements from capture sites. Our largest movement was a young male, BC37, who was relocated approximately 68 km west of his capture site. A juvenile female, BC03, established a home range approximately 43 km north of her capture location. The center of a male juvenile's, BC20, home range was approximately 48 km south of his capture site; which encompassed a major tributary crossing, the Belle Fourche River. We observed an 80% ($n=8$) dispersal rate among juveniles; mean distance dispersed was 21.8 km (range 5.0–46.3 km).

Discussion

Our results indicated that male and female bobcats covered large expanses of land along tributaries in western South Dakota. Core areas were found near waterways or in drainages near a water source. Adult bobcats tended to remain in the area where they were captured, with the exception of BC05, whereas juvenile bobcats dispersed from natal ranges, at times by great distances. We hypothesized that home range size would differ between sexes, but not among years. There was no significant difference in home range size between 2014 and 2015 in females, whereas adult male bobcat home ranges were greater than adult females. Home range size of adult male bobcats was approximately 2.7 times larger than adult female bobcats in west-central South Dakota, which is comparable to Iowa (Koehler 2006) and the Badland and Black Hills regions of South Dakota (Mosby 2011). We were unable to compare home range size of adult males in 2014 and 2015 because of a low sample size in 2014. We found no significant difference between home range size of adult females in 2014 and 2015.

Large home range size may be a function of meeting biological needs with available habitat. The majority of the study area was dominated by graminoids and herbaceous cover (78.5%); we observed bobcats located near shrub and forested lands, which accounted for approximately 7.0% of the study area (USDA GeoSpatialDataGateway 2014). Mosby (2011) correlated a relationship between wooded cover and rugged river break terrain as important habitat for bobcats. Our adult male and female bobcat home range size estimates were similar to those for bobcats of the Badlands region (Table 2), whereas bobcats in the Black Hills and Bon Homme regions of South Dakota had smaller home range sizes (Mosby 2011). Additionally, home range estimates of adult female bobcats along the Bad River of South Dakota were similar to our estimates (Fredrickson and Mack 1995). Previous bobcat studies in South Dakota that documented home range size used different home range estimators; however, general comparisons of home range sizes suggest the area a bobcat occupied varied throughout South Dakota.

Home range size of bobcats in northern latitudes are considerably larger than in southern latitudes (Anderson and Lovallo 2003). Our data indicated that female and male bobcats are using similar amounts of area as those reported in Maine (Litvaitis et al. 1986) and Wisconsin (Lovallo and Anderson 1996). Bobcats in Iowa (Koehler 2006) had slightly smaller home ranges for males and females; 55.3 km^2 and 19.9 km^2, respectively.

Our home range size estimates were near the higher end of reported estimates; however, Knick (1990) documented larger home range sizes in Idaho during a lagomorph shortage in 1984–1985. The larger home range size seen in our region may indicate that bobcats require a larger area due to limited forested and shrub lands or prey densities present in the study area.

Bobcat body size generally follows Bergmann's rule, with size increasing with latitude and elevation (Sikes and Kennedy 1992). Adult bobcat weights vary throughout their range with males averaging 9.6 (6.4–18.3) kg and females averaging 6.8 (4.1–15.3) kg (Anderson and Lovallo 2003). Our mean weight of captured bobcats was similar to bobcats collected in Maine (Litvaitis et al. 1986). Adult bobcats captured in our study area were approximately 1.2 times larger than the average weight of bobcats throughout their range.

It has been documented that declining prey densities can influence predator home range sizes (Ward and Krebs 1985, Litvaitis 1986, Knick 1990). We hypothesized that intraspecific competition between bobcats plays an important role in home range size. In 2014, BC21 and BC22 had the largest two home ranges for our study animals; we observed a 37% overlap in home range between the two individuals. During the 2014-2015 bobcat harvest season BC21 was harvested which relieved competition pressure and in 2015 BC22's home range decreased from 79.2 km^2 in 2014 to 8.6 km^2 in 2015. We documented another large female home range, in 2014, of 80.1 km^2 (BC36), but were unable to capture another female in her area. During the 2014-2015 bobcat harvest season an adult female was harvested in BC36's home range by a trapper (S. Lynch; Faith, SD). In November 2014, we captured an adult female bobcat (BC29) and within a month it moved along a tributary encroaching on BC05's established territory. Approximately one month after BC29 entered BC05's territory, BC05 traveled west along the tributary to a potential vacant territory, which may have provided seclusion from BC39. Generally, individual bobcats move to new ranges when adjacent individuals die or due to a lack of food resources in their current home range (Anderson and Lovallo 2003). These observations suggest intraspecific competition for resources; prey densities were not studied, but we hypothesize prey was the limiting factor influencing home range size.

During a prey decline in Idaho, Knick (1990) observed two adult male bobcats increase their annual home ranges during the decline; from 1982–1983, MA23 encompassed an area of 18.5 km^2 and in 1984–1985 home range increased to 95.3 km^2. Additionally, annual home range size for MA77 was 39.1 km^2 in 1983–1984 and 163.1 km^2 in 1984–1985. We encountered 3 adult male bobcats with a home range size similar to those observed in Idaho during a lagomorph decline (Knick 1990). The mean home range size of adult males in our study was 1.6 times larger than the Black Hills estimates, and 1.2 times larger than the Bon Homme county estimates (Mosby 2011). In a low density population, males may increase home range size to maximize breeding opportunities, whereas female home range size likely varies in relation to prey density (Kamler and Gipson 2000, Mosby 2011). Drought is another factor that has been documented affecting home range size of carnivores (Pereira et al. 2006; Moyer et al. 2007). During a severe drought in Argentina, the brown hare (*Lepus europaeous*) population decreased 9-fold in one year and the Geoffroy's cat (*Oncifelis geoffroyi*) subsequently increased home range 9-fold to meet metabolic requirements (Pereira et al.

2006). In 2013, western South Dakota was in a severe drought (USDM 2016). We do not know home range size prior to 2013; however, we did not see a change in home range or core area size of adult female bobcats in 2014 and 2015. We can only speculate that the drought in 2013 negatively affected prey densities and, therefore, would have caused the large home range sizes documented in the region.

Prey density can directly affect carnivore home range size, recruitment, and survival (Ward and Krebs 1985, Knick 1990). Large home ranges and dispersal distances from natal range support the hypothesis that prey densities in our study were likely low. Maintenance of large home ranges increases energy expenditures and may affect the survival or fitness of individuals. Litvaitis et al. (1986) observed a higher density of snowshoe hares (*Lepus canadensis*) and bobcats in habitat with a thick understory and avoidance by bobcats of sparsely vegetated areas. Habitats along tributaries are likely to have understory components supporting higher densities of prey compared with hay or pasture lands. Our home ranges and core areas were located next to tributaries and waterways, possibly supporting the hypothesis that bobcats were selecting areas with a higher prey density.

Kamler and Gipson (2000) classified bobcats >18 months of age as adult, young adult (e.g., < 24 months) bobcats may not have established home ranges. Two of the three largest male home ranges were observed in 2015 (BC14 and BC20), were for bobcats that were approximately 20 months old when they started to establish home ranges. These two young adults may have been in the process of establishing home ranges, which could contribute to the large utilization distributions (UDs) documented. Juvenile bobcats traverse the landscape looking for vacant territories or resources that meet the metabolic needs of the individual (Benson et al. 2004). Juvenile male bobcats are more likely to leave natal range to avoid inbreeding and resource competition (Janečka et al. 2007). Males averaged 30.6 km between natal areas and established home ranges, whereas females averaged 23.1 km. Bobcat BC03 was relocated 46.3 km from the center of her established home range to her capture site. Knick (1990) documented females dispersing 22.1 km on average from natal range during a period of prey decline. Juvenile home range estimates in our study area were highly variable; random movements and large distances traversed between locations create greater bandwidths around each data point. Therefore, caution is advised when using juvenile home ranges for density estimates.

Management Implications

Bobcats in west-central South Dakota established large home ranges, likely to meet metabolic needs and increase fitness. The requirements of maintaining a large home range would increase vulnerability to trapping and energy expenditures, potentially affecting body condition. We observed juvenile bobcats dispersing large distances potentially affecting kidney fat reserves and increasing likelihood of human interactions. Our results suggested lands surrounding tributaries are important habitats for bobcats. Pasture and hay land dominate the landscape, concentrating bobcats in rugged river breaks and along waterways. We documented potential intraspecific competition among females, which may have resulted in large home range sizes. It is important to conserve the limited habitat along tributaries in west-central South Dakota. Fragmentation or degradation of riparian habitats may have a negative impact on bobcats found in western South Dakota.

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Figure 1. Study area in which bobcats were captured, located in west-central South Dakota, which include Butte, Meade, Pennington, and Perkins counties, South Dakota.

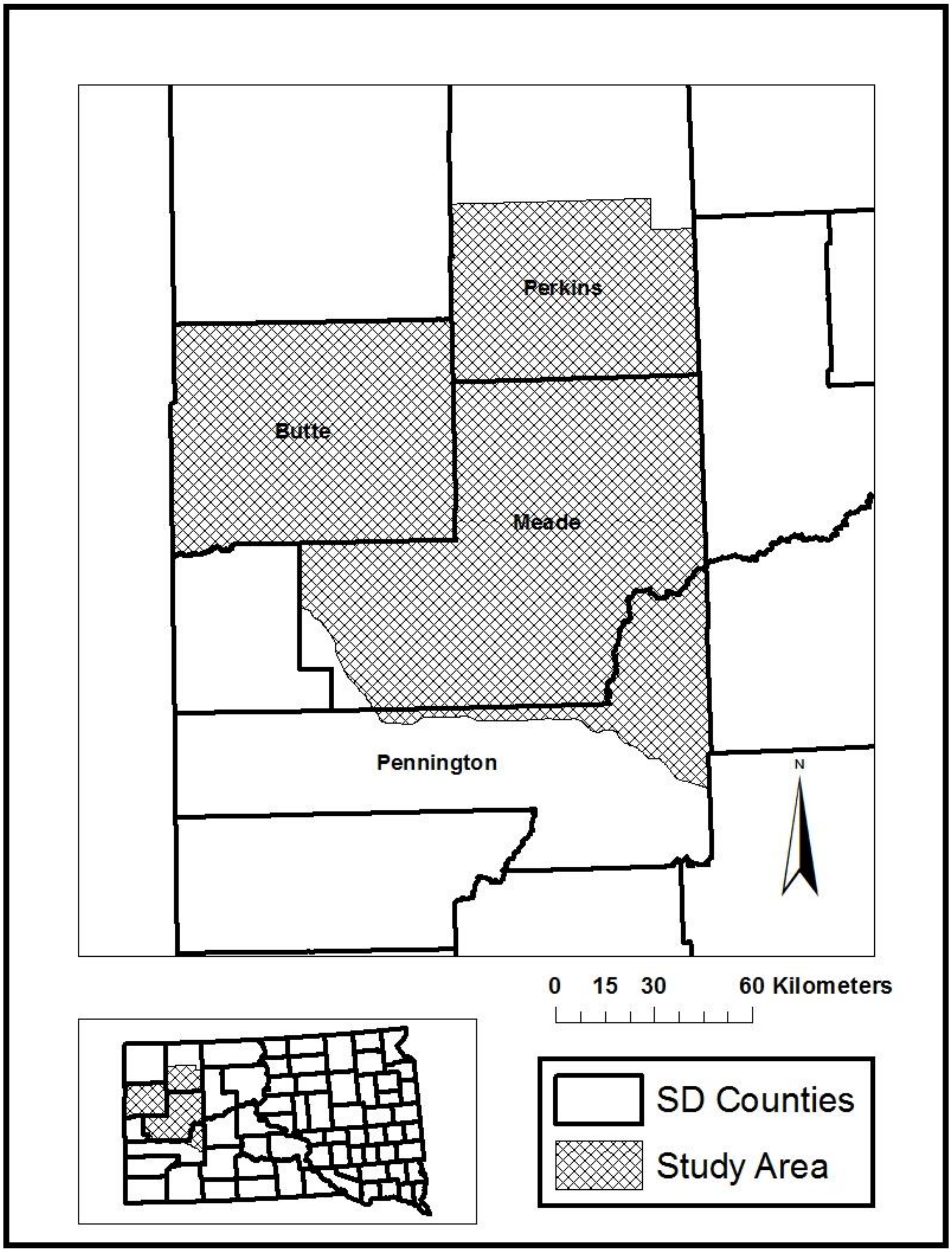

Table 1. Mean home range (95% UD) and core (50% UD) size (km^2) of bobcats in western-central South Dakota from 2013-2015.

	2014		2015		All		
	F	M	F	M	F	M	J
No. of individuals	9	2	14	9	16	10	10
Mean no. of locations	27.9	29.5	22.6	21.8	48.1	49.7	19.1
Mean home range size	39.7	91.4	20.6	83.1	29.4	80.0	72.3
Mean core size	9.1	22.5	4.9	21.4	7.1	19.7	-

Table 2. Mean and SE values for bobcat home ranges in the Badlands (2006–2007), the Black Hills (2007–2008), Bon Homme County (2008–2009) in South Dakota, USA (Mosby 2011) and West-Central, South Dakota (2012–2015).

	Female		Male	
Study Area	(km^2)	SE	(km^2)	SE
Badlands	26.7	7.3	72.1	17.7
Black Hills	18.8	5.1	49.9	7.4
Bon Homme	16.0	8.2	64.7	12.6
West-Central, SD	29.4	4.9	80.0	12.2

CHAPTER 4: REPRODUCTIVE RATE, FOOD HABITS, AND NUTRITIONAL CONDITION OF BOBOCATS IN SOUTH DAKOTA

ABSTRACT - Bobcat (*Lynx rufus*) population characteristics in South Dakota can vary locally and annually; however, sparse information is available on populations inhabiting western South Dakota. We collected 1,208 carcasses of bobcats that were legally harvested from 2012 to 2015 in South Dakota. The highest statewide reproductive rate was during the 2012-2013 season (placental scars; 1.87, SE = 0.10), which was statistically higher ($P < 0.001$) than for bobcats harvested during the 2013–2014 season. The 2013–2014 season was the least productive season, with the lowest pregnancy (46.9%) and reproductive rates (1.14, SE = 0.14). The Kidney Fat Index progressively declined annually throughout the study; values for the 2014–2015 season were statistically less ($P < 0.001$) than prior years. Although both indices declined temporarily, there was little correlation between the Kidney Fat Index and number of placental scars ($r^2 = 0.02$). Our findings support a prey population decline based on low reproductive rates and declining Kidney Fat Index; however, the 2014–2015 bobcat harvest season indicated an increase in reproductive rates potentially signifying that the population has the potential to rebound.

INTRODUCTION

Historically, bobcats occurred in all 48 contiguous states, and expanded into Canada in the past century (Anderson and Lovallo 2003). Prior to 1970, bobcats in North America were of low economic importance (Hanson 2007), but the passing of the Endangered Species Act (ESA) in 1973 and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1975 prohibited trade of African spotted cats, which consequently increased demand for other spotted fur (Anderson and Lovallo 2003; Hanson 2007). Bobcats became popular because of their thick spotted belly fur, and harvest numbers began to rise across their range (McMahan 1986; Kitchener 1991). From 2010 to 2014, the United States of America, Canada, and Mexico exported 431,931 bobcat pelts throughout the world (CITES 2015).

With a high demand for bobcat pelts, managing agencies are tasked with understanding the components of bobcat life-histories that ensure sustainable populations. Managing agencies have used placental scar counts on uteri of female mammals to monitor population status and estimate litter size and pregnancy rates (Mowat et al. 1996). Recruitment refers to the addition of new individuals added to the breeding population via reproduction (Dinsmore and Johnson 2005). Understanding annual variation in recruitment is a crucial to understanding and managing exploited populations. Bobcats produce one to six kittens, commonly in the spring months (Hanson 2007). There is evidence of 1-year old females ovulating in Arkansas, however, they failed to become pregnant (Fritts and Sealander 1978). Crowe (1975) believed first-time breeders may ovulate later than mature females and contribute to late litters. In Idaho, Knick (1990) observed female bobcats 12–15 months old that did not successfully raise kittens, however, adult females produced 1–3 kittens during a prey population decline. Bobcats had fewer litters during a period of low jackrabbit (*Lepus californicus*) and cotton-tail rabbit (*Sylvilagus nuttallii*) abundance, but average litter size did not vary between years with prey shortages and abundances (Knick 1990). Knowledge of body condition may also be used to assess the health and nutritional status a population (Winstanley et al. 1998). Reproductive potential has been linked to body fat content, especially in Cervids (Thomas 1982; Cook et al. 2004); however, health assessments has not been conducted for bobcats as a means of assessing reproductive potential.

Lagomorphs are considered an important food item throughout their geographic range; however, bobcat diets can vary annually and regionally. In south Texas, the majority of prey consumed by bobcats was comprised of cotton rats (*Sigmodon hispidus*; Beasom and Moore 1977); whereas, in Georgia the marsh rabbit (*Sylvilagus palustris*) was the major component in the diet of bobcats (Baker et al. 2001). In the northern range of bobcats, snowshoe hare (*Lepus americanus*) and white-tailed deer (*Odocoileus virginianus*) predominate in the diet of bobcats (Pollack 1951; McLean et al. 2005). Stomach contents of bobcats in western Washington contained primarily mountain beaver (*Aplodontia rufa*), whereas, a more diverse diet in eastern Washington included lagomorphs (*Sylvilagus nuttalii*, *Lepus* spp.), red squirrels (*Tamiasciurus douglasi*), deer (*Odocoileus* spp.), and voles (*Microtus* spp.; Knick et al. 1984).

Bobcat harvest numbers in South Dakota have varied since the implementation of the first harvest season in 1975 (Broecher 2012). Factors influencing population change from year to year and identifying variables that affect reproduction potential can help managers predict future population trends. Placental scars and food habits of bobcats have been previously documented in South Dakota. Nomsen (1982) and Mosby (2011) documented lagomorphs as an important prey species for bobcats in South Dakota. Nomsen (1982) analyzed reproductive tracts of sexually mature female bobcats, which averaged 2.7 (range 1–5) placental scars; carcasses where obtained through legal harvest on lands west of the Missouri River. Reproductive potential and relative health assessments are important factors that need to be addressed for population modeling purposes and an overall status of bobcat condition in South Dakota. Therefore, our objectives were to: 1) document recruitment via placental scar counts; 2) estimate pregnancy rates; 3) calculate a Kidney Fat Indices; 4) assess the relationship between condition and reproduction; and 5) calculate frequency of occurrence of diet items.

STUDY AREA

Our study area encompassed lands west of the Missouri River and five counties bordering the river to the east (Figure 1). The Black Hills, plains west of the Missouri River, and northern mixed grass prairie east of the Missouri River make up the three distinct ecotypes present in our study area. The majority of the land west of the Missouri River is part of the Northern Wheatgrass-Needlegrass Plains (Johnson and Larson 1999). The Northern Wheatgrass-Needlegrass Plains are characterized as a grassland with scattered buttes and badlands formations with large expanses of intact native rangeland (Johnson and Larson 1999). Herbaceous cover throughout the region includes western wheatgrass (*Pascopyrum smithii*), blue gramma (*Bouteloua gracilis*), crested wheatgrass (*Agropyron cristatum*), smooth brome (*Bromus inermis*), and little bluestem (*Andropogon scoparius*); additional forb species are western snowberry (*Symphoricarpos occidentalis*), leadplant (*Amorpha canescens*), and Missouri goldenrod (*Solidago missouriensis*; Johnson and Larson 1999). Rivers and streams dissect the western South Dakota plains creating an environment for woodland species including plains cottonwood (*Populus deltoides*), a hybrid of Rocky Mountain Juniper (*Juniperus scopulorum*) and Eastern red cedar (*Juniperus virginiana*; Van Haverbeke 1968, Ode 1990), burr oak (*Quercus macrocarpa*) and green ash (*Fraxinus pennsylvanica*). Average annual precipitation for the region is 47 cm; mean temperatures ranged from -9° C in January to

33° C in July (National Oceanic and Atmospheric Administration [NOAA] 2015). Climate values were based on data collected at the Interior, South Dakota weather station from 1981-2010 (NOAA 2015).

The counties east of the Missouri River are included in the Northern Mixed-Grass Prairie ecotype; the region was formed on glacial till, which created productive farmland (Johnson and Larson 1999). While little native prairie still exists, grasses present include western wheatgrass, big bluestem (*Andropogon gerardii*), little blue stem, and smooth brome; forbs include cudweed sagewort (*Artemisia ludoviciana*), purple coneflower (*Echinacea angustifolia*), and Missouri goldenrod interspersed throughout the area (Johnson and Larson 1999). Drainages and draws along the Missouri River are dominated by eastern red cedar (*Juniperus virginiana*), green ash, and plains cottonwood. Average annual precipitation was 69 cm; mean temperatures ranged from -12° C in January to 31° C in July (National Oceanic and Atmospheric Administration [NOAA] 2015). Climate values were based on data collected at the Yankton, South Dakota weather station from 1981-2010 (NOAA 2015).

The Black Hills are an isolated mountain range located in the Northern Great Plains (Hoffman and Alexander 1987). Elevation ranges from 1050–2207 m above mean sea level (Brown and Sieg 1999). Temperatures in the Black Hills range from -12 to 30°C and average annual precipitation is 48 cm (Driscoll et al. 2000). Forests are dominated by ponderosa pine (*Pinus ponderosa*–between 1050–2150 m elevations), which are gradually replaced at lower elevations (<1050 m) by deciduous woodlands (Cryon et al. 2000). Understory is comprised of common snowberry (*Symphoricarpos albus*), serviceberry (*Amelanchier alnifolia*), and cherry species (*Prunus* spp.);

herbaceous vegetation included western wheatgrass, smooth brome, sun sedge (*Carex inops*), and little blue stem (Larson and Johnson 1999).

METHODS

Data Collection

Carcasses were collected intact from legally harvested bobcats from 2012 to 2015 during bobcat trapping and hunting seasons and were sent to South Dakota State University or to the South Dakota Department of Game, Fish and Parks regional office in Rapid City, South Dakota and frozen until necropsied. During necropsy, each carcass was sexed, lower canines collected for aging, reproductive tracts extracted from females, stomachs analyzed for diet items, and kidneys with connected fat tissue removed.

We thawed carcasses in a heated shop approximately 24 hours before necropsy. We removed lower jaws from bobcat carcasses and were boiled them to extract both lower canines, which were shipped to Matson's Laboratory (Manhattan, MT, USA) for aging. Bobcat carcasses were cut open using dissecting scissors. We removed all contents from stomachs and identified food items by hair type and color, bone, and feathers. Unidentified stomach contents where frozen in whirl packs to be identified at a later date. We removed reproductive tracts from females and froze them in water for later scoring (Mowat et al. 1996) and removed kidneys with surrounding fat tissue (Riney 1955).

We thawed reproductive tracts in warm water until thawed. We cut uteri lengthwise and examined them internally for placental scars. When macroscopic identification of food items was not possible, we attempted to identify unknown mammal hairs to species using a reference key developed for Wyoming mammals (Moore et al. 1974). We recorded all food items in terms of percent frequency of occurrence. We cut fat tissue attached to the kidney perpendicularly to both ends (*See* Riney 1955), and used a Ohaus Scout Pro Balance scale (Ohaus Corporation, Parsippany, NJ, USA) to weigh kidneys and kidney fat (separately) to the nearest 0.1 gram.

Data Analysis

Bobcat carcasses with missing CITES tags were omitted from all analyses, whereas bobcats with missing tissue data (e.g., KFI) were removed from specific analyses. We counted 6 classes of placental scars that ranged from light to dark black (Englund 1970; Lindstrom 1981); all scars were included in our analysis. Female bobcats <1 year of age are not sexually mature (Crowe 1975) and were excluded from pregnancy and recruitment rate analyses. We separated South Dakota into three ecotypes for analysis (Black Hills, West River, and East River). Pregnancy rates were calculated by summing the number of reproductive tracts with at least one placental scar divided by the total number of sexually mature females. The Kidney Fat Index was calculated by weighing the fat cut perpendicular from both kidneys divided by the weight of both kidneys and include all age classes and both sexes. We used an analysis of variance (ANOVA) to test for a difference in means of the Kidney Fat Index and placental scars over the 3-year period, and used Tukey's HSD for pairwise comparisons. We used a linear regression model to correlate number of placental scars and Kidney Fat Index. We conducted statistical tests using Program R version 3.1.2 with an experimental error rate of 0.05.

We classified stomach items into eight categories: lagomorphs, mammals (*Mustelidae, Erethizontidae, Cricetidae*, *Heteromyidae*, *Geomyidae*, *Sciuridae, Soricidae*), birds (*Meleagrididae*, *Phasianidae*), ungulate (*Cervidae*, *Antilocapridae*), parasite, vegetation, unknown, and empty. We calculated percent occurrence by summing the number of individual stomachs containing a given food category (i.e., number of stomachs containing lagomorphs), dividing this sum by the total stomachs that contained food items, then multiplying by 100. Stomachs may contain more than one food item.

RESULTS

We collected and necropsied 1,208 carcasses of legally harvested bobcats during 2012–2015. We analyzed 425 adult female reproductive tracts to estimate pregnancy and recruitment rates. Our highest documented placental scar counts occurred in the 2012–2013 harvest season and our lowest count was in 2013-2014 (Table 1). Bobcats that produced a litter averaged 2.7 kittens/female. Pregnancy rate for bobcats was highest in carcasses collected during the 2014–2015 season and least during the 2013–2014 harvest season (Table 2). The Kidney Fat Index declined for bobcats temporally, with carcasses from the 2014–2015 season averaging the lowest Kidney Fat Index (Table 3). No relationship was documented between the Kidney Fat Index of adult female bobcats and number of placental scars ($r^2 = 0.02$, $F = 7.30$, Figure 2). We noted a significant difference between the average number of placental scars by year ($F = 7.74$, $df = 2$, $P < 0.001$, 95% CI); the 2012–2013 harvest season was statistically greater ($P < 0.001$) than the 2013–2014 harvest season. We collected and analyzed 1,071 useable kidney samples from legally harvested bobcats and found annual differences in the Kidney Fat Index over the three years (F = 14.91, df = 2, P<0.001, 95% CI); the 2014-2015 season produced the lowest Kidney Fat Index, followed by the 2012-2013 (P < 0.001) and 2013–2014 (P = 0.006) harvest seasons. We collected 1,096 stomachs for diet analyses. Annually, lagomorphs comprised the largest percent frequency of stomach contents, except for those collected on lands east of the Missouri River during the 2014–2015 harvest season (*n* = 7). We documented an annual increase in occurrence of empty stomachs in counties west of the Missouri River. Lagomorph frequency of occurrence varied annually and regionally; however, the 2014–2015 harvest season had the lowest percent of lagomorphs in bobcat stomachs (Tables 4, 5, 6). The Kidney Fat Index of adult male and female bobcats decreased annually in our study area (Figures 3, 4, 5).

DISCUSSION

Recruitment is a crucial parameter to understand when managing a sustainable bobcat population. Litter size from 2012 to 2015 was similar to that previously documented by Nomsen (1982), but our estimate also included bobcats collected from east of the Missouri River, South Dakota. Our average litter size (2.7) was comparable to placental scar counts of 2.5 and 2.8, which were previously documented in Arkansas and Wyoming, respectively (Crowe 1975; Fritts and Sealander 1978). We included all placental scars in our analysis regardless of the shade observed. Our estimates are based on scars visible when observing the uteri and we were unable to predict which scars were remnants of absorbed or aborted fetuses; therefore, our placental scar counts may be biased high. For management purposes, we calculated a recruitment rate using all female reproductive tracts, including uteri without placental scars. Our placental scar counts likely suggest the highest number of kittens born was in 2012, whereas 2013 produced the fewest kittens. The statewide pregnancy rate was lowest in 2013, but the following year produced the highest rate for our study.

Female bobcats in Idaho produced fewer litters when jackrabbit and cottontails were scarce compared to years when they were abundant (Knick 1990). The aforementioned trend is comparable to the Black Hills region of South Dakota in that percent frequency of occurrence of lagomorphs declined annually, along with the corresponding pregnancy rates. However, the lands east and west of the Missouri River (excluding the Black Hills) had pregnancy rate estimates increase or remain constant during the 2014–2015 bobcat harvest season, when we observed lower frequency of occurrence of lagomorphs in the diet. Previous research found mean in utero litter size changed relatively little with food supply, whereas pregnancy rates were affected by prey availability (Mowat et al. 1996). In 2014–2015, we documented the highest statewide pregnancy rate and frequency of occurrence of empty stomachs. Energy expenditures increased when small mammals replaced lagomorphs during a decline in Idaho (Knick 1990). We did not measure prey abundance during the project, but hypothesize prey density was an important variable affecting pregnancy rates in bobcats in South Dakota.

Bobcats collected from the 2014–2015 season accumulated the least amount of kidney fat compared to the 2 previous seasons. The mean Kidney Fat Index decreased temporally across each ecotype in South Dakota, suggesting bobcat fat deposits throughout the state were progressively declining. Additionally, adult male and female bobcats were separated into respective KFI classes; KFI declined annually for both sexes in our study area. Adult male KFI was higher, on average, compared to females in the same ecotype. A combination of harsh winter conditions and a lagomorph shortage caused two female bobcats in Idaho to lose approximately 40% of previous capture weight and both carcasses had no significant fat deposits (Knick 1990). However, the relationship between the Kidney Fat Index and the number of placental scars was not significant in our study. Analyzing the Kidney Fat Index during the bobcat harvest season may not represent the reproduction potential from the previous year because health condition prior to breeding can influence fertility. Studies focusing research on nutritional condition and reproduction collected data during or post conception with respect to breeding seasons (Noyes et al. 2002; Cook et al. 2004). Carcasses need to be collect during parturition to understand reproduction potential based on Kidney Fat Index.

Results from our study showed an annual decline in lagomorph consumption and a decline in prey availability could account for the lack of lagomorphs in the diet. In addition, the drought in 2013 (USDM 2016) could have been responsible for a decline in prey species resulting in the increase of empty stomachs in our study. In Idaho, female bobcats expended more energy to travel further and forage on lower quality prey species (small mammals) while rearing young, which negatively affected fat stores (Knick 1990). We documented (*see* Chapter 3) large home ranges for radio-collared bobcats that possibly were associated with low prey availability. In a previous study, captive coyotes (*Canis latrans*) consumed approximately 46 times more mice to equal the same energy output of snowshoe hares (*Lepus americanus*) annually, to meet minimum metabolic requirements (Litvaitis and Mautz 1980). A decrease in lagomorph densities and large home ranges may potentially explain the declining trend in the Kidney Fat Index in our study area.

MANAGEMENT IMPLICATIONS

In South Dakota, body fat reserves declined annually and a decline in lagomorph remains in stomach contents and an increase in empty stomachs, suggests prey availability declined during the study. Lagomorph densities are likely the driving factor affecting population size, which may vary annually from drought and winter severity. Kidney Fat Index declined annually potentially indicating the bobcat population is near carrying capacity with regard to food resources available. Higher lagomorph densities would likely increase reproductive potential and allow bobcats to meet their life history requirements. The adult female bobcat Kidney Fat Index was lower than for males, likely reflecting the higher metabolic need of female bobcats while rearing young. Pregnancy rates in the Black Hills region declined annually; however, we documented an increase in placental scars in the last year of the study. An increase in pregnancy rates and placental scars on lands east and west of the Missouri River (excluding the Black Hills) suggested reproduction potential was recovering. Bobcat stomachs contained different prey items across South Dakota; however, the highest occurrence of food items was for lagomorphs, indicating they were an important prey item during winter months. Future studies should focus on lagomorph populations and how they affect bobcat reproduction potential.

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Figure 1. Region of harvest and no harvest in South Dakota, USA.

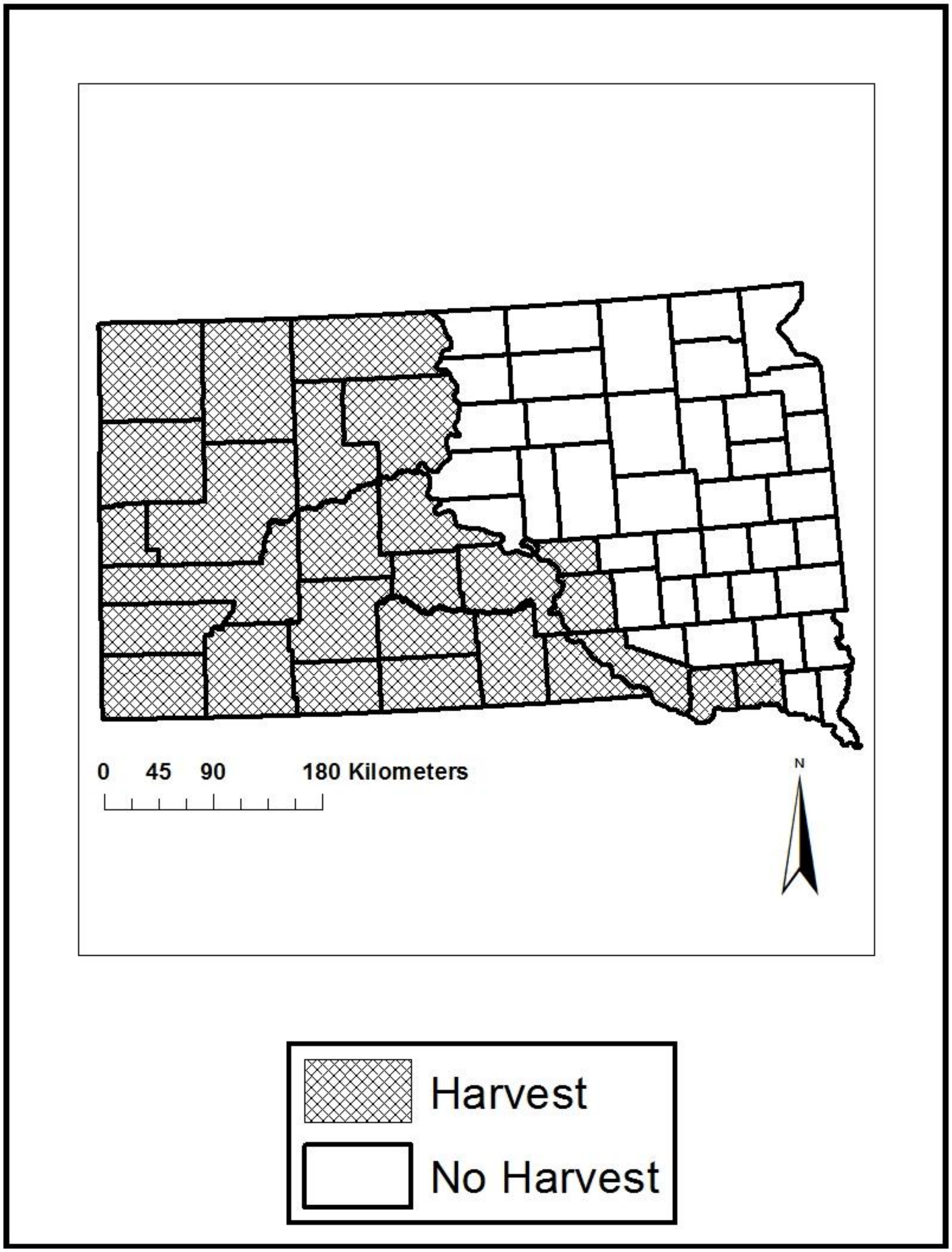

Table 1. Placental Scar counts from adult female bobcats legally harvested in South Dakota from 2012 to 2015.

	2012-2013		2013-2014		2014-2015		Total	
	Mean	SE	**Mean**	SE	**Mean**	SE	**Mean**	SE
SW	**1.87**	0.10	**1.14**	0.14	**1.53**	0.20	**1.65**	0.08
ER	**2.79**	0.43	**1.83**	0.91	**1.50**[a]	1.06	**2.41**	0.39
WR	**1.80**	0.11	**1.05**	0.16	**1.57**	0.22	**1.60**	0.09
BH	**1.93**	0.23	**1.27**	0.27	**1.30**	0.54	**1.64**	0.18

SW: Statewide

ER: East of the Missouri River

WR: West of the Missouri River (excluding Black Hills)

BH: Black Hills

[a] n = 2 adult females collected

Table 2. Pregnancy rate (%) from legally harvested adult female bobcats in South Dakota from 2012 to 2015.

	2012-2013	2013-2014	2014-2015
SW	56.9	46.9	59.4
ER	88.2	50.0	50.0[a]
WR	53.1	44.0	61.5
BH	68.6	60.0	50.0

SW: Statewide

ER: East of the Missouri River

WR: West of the Missouri River (excluding Black Hills)

BH: Black Hills

[a] n = 2 adult females collected

Table 3. Kidney Fat Index from legally harvest bobcats in South Dakota from 2012 to 2015.

	2012-2013	2013-2014	2014-2015
ER	0.61	0.27	0.23
WR	0.75	0.67	0.42
BH	1.20	0.74	0.40

ER: East of the Missouri River

WR: West of the Missouri River (excluding Black Hills)

BH: Black Hills

Table 4. Percent frequency of occurrence of food items identified from stomachs of bobcats legally harvested west of the Missouri River, South Dakota (excluding Black Hills).

	2012-2013	2013-2014	2014-2015
Empty	28	32	54
Lagamorph[a]	28	31	25
Mammal[b]	14	15	13
Bird[c]	14	11	3
Ungulate[d]	3	5	3
Vegetation	27	23	30
Parasites	63	58	36
Unknown	1	1	1

[a]lagomorph = *Sylvilagus* and *Lepus spp.*; [b] mammal = *Mustelidae, Erethizontidae, Cricetidae, Heteromyidae, Geomyidae, Sciuridae, Soricidae*; [c] bird = *Meleagrididae, Phasianidae*; [d] ungulate = *Cervidae, Antilocapridae*.

Table 5. Percent frequency of occurrence of food items identified from stomachs of bobcats legally harvested in the Black Hills, South Dakota.

	2012-2013	2013-2014	2014-2015
Empty	26	38	57
Lagamorph[a]	34	32	24
Mammal[b]	17	14	11
Bird[c]	14	0	0
Ungulate[d]	6	10	5
Vegetation	25	28	22
Parasite	65	52	32
Unknown	0	2	3

[a]lagomorph = *Sylvilagus* and *Lepus spp.*; [b] mammal = *Mustelidae*, *Erethizontidae*, *Cricetidae*, *Heteromyidae*, *Geomyidae*, *Sciuridae*, *Soricidae*; [c] bird = *Meleagrididae*, *Phasianidae*; [d] ungulate = *Cervidae*, *Antilocapridae*.

Table 6. Percent frequency of occurrence of food items identified from stomachs of bobcats legally harvested east of the Missouri River, South Dakota.

	2012-2013	2013-2014	2014-2015
Empty	63	38	71
Lagamorph[a]	17	25	0
Mammal[b]	9	6	14
Bird[c]	14	19	0
Ungulate[d]	3	13	14
Vegetation	40	31	43
Parasite	34	50	57
Unknown	0	0	0

[a]lagomorph = *Sylvilagus* and *Lepus spp.*; [b] mammal = *Mustelidae*, *Erethizontidae*, *Cricetidae*, *Heteromyidae*, *Geomyidae*, *Sciuridae*, *Soricidae*; [c] bird = *Meleagrididae*, *Phasianidae*; [d] ungulate = *Cervidae*, *Antilocapridae*.

Figure 2. Linear regression model comparing placental scars and condition index from legally harvested adult female bobcats in South Dakota from 2012 to 2015.

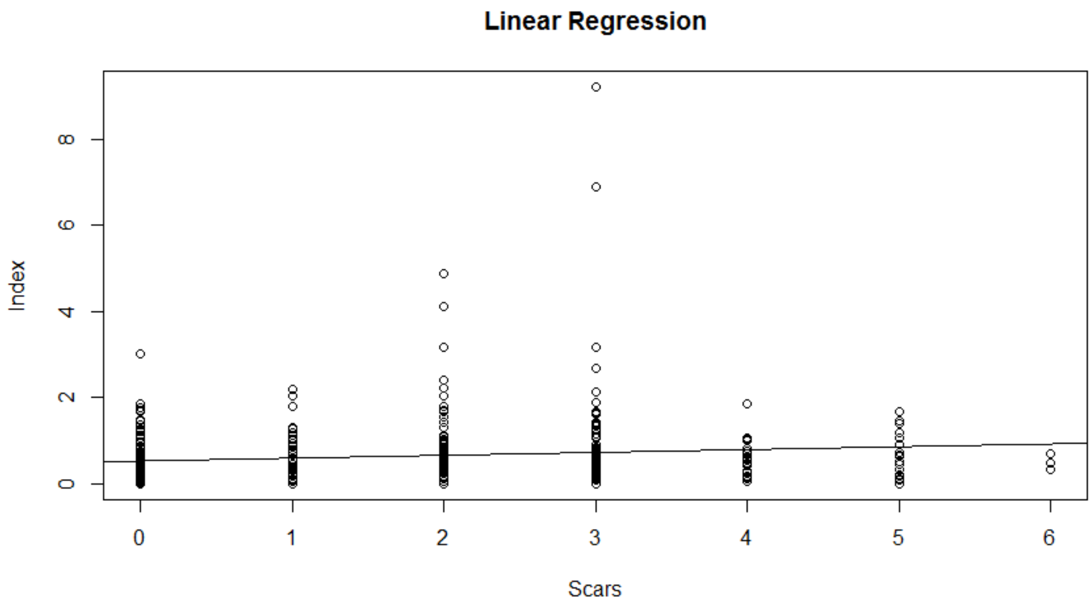

Figure 3. Kidney Fat Index of adult males and females harvested in 2012-2015 from lands east of the Missouri River, South Dakota.

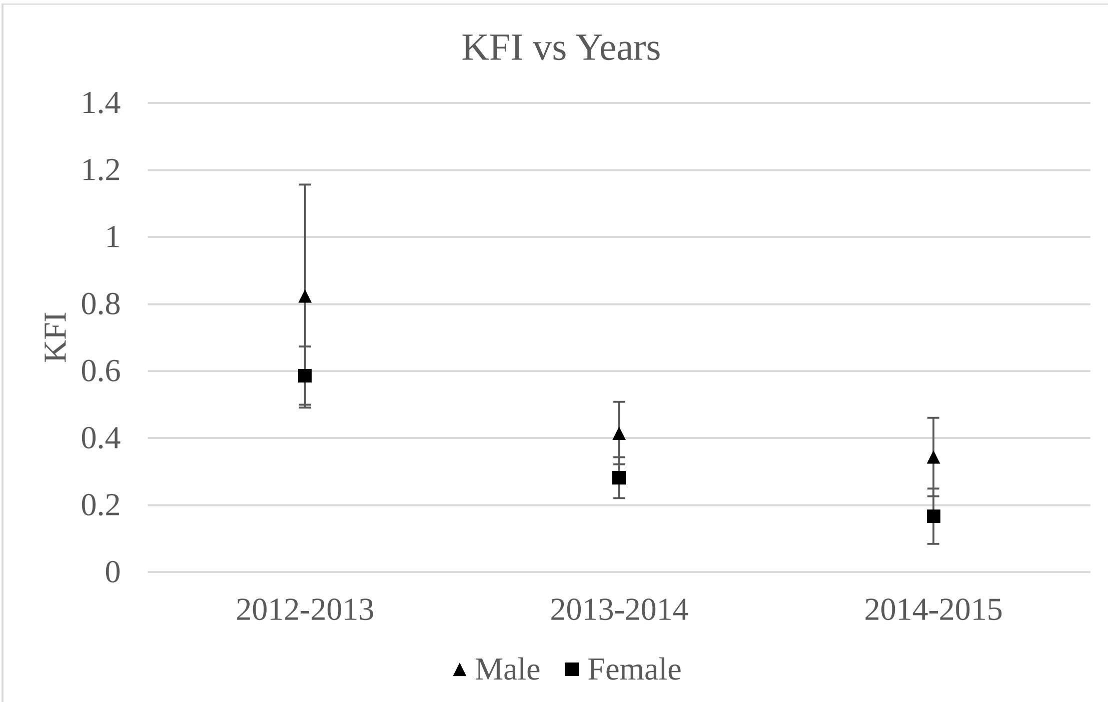

Figure 4. Kidney Fat Index of adult males and females harvested in 2012-2015 from the Black Hills, South Dakota.

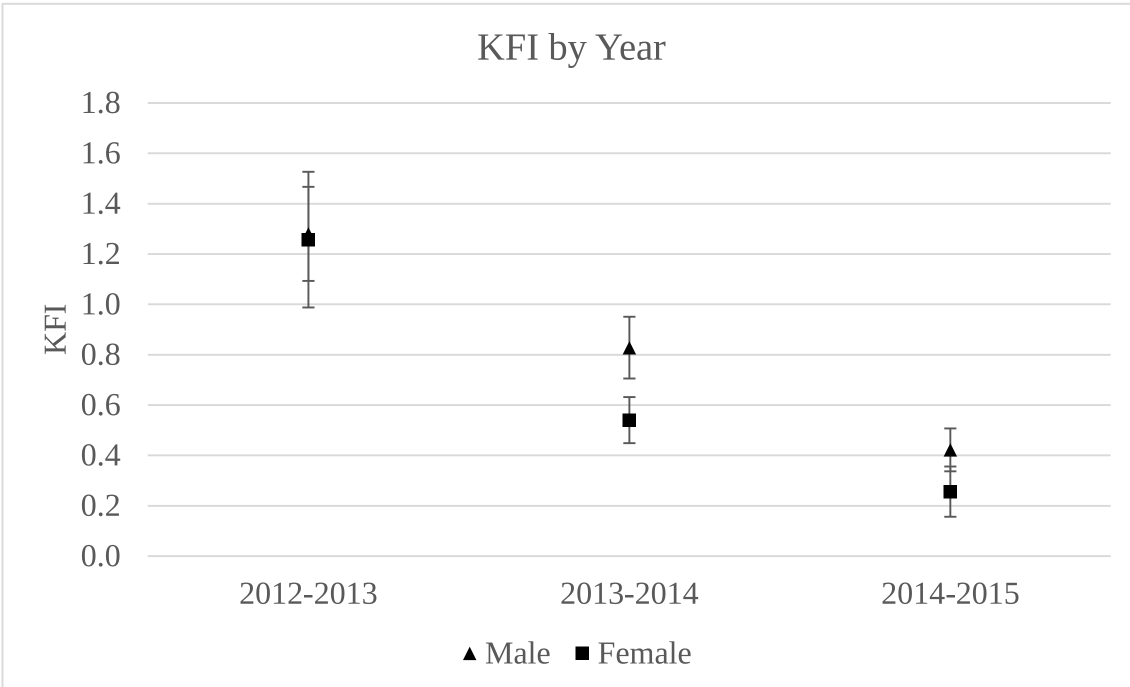

Figure 5. Kidney Fat Index of adult males and females harvested in 2012-2015 from lands west of the Missouri River, South Dakota.