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STATUS OF THE BOBCAT IN ILLINOIS

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FINAL REPORT

Federal Aid Project W-126-R-7

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FINAL REPORT

STATE OF ILLINOIS

W-126-R-7

Project Period: 1 July 1999 through 30 June 2002

Project: Status of the Bobcat in Illinois

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NEED: The bobcat (*Lynx rufus*) was first protected in Illinois in1972 and was placed on the state threatened species list in 1977 (Rhea 1982). Past research by the Cooperative Wildlife Research Laboratory at Southern Illinois University at Carbondale has compiled historical and current sighting data to determine distribution and relative abundance of bobcats in Illinois (Rhea 1982, Gibbs 1998) and studied basic ecology of radio-collared bobcats (Woolf and Nielsen 1999). During 1999, bobcats were de-listed as a state threatened species, beginning a new era in bobcat management in Illinois. More information is necessary to further understand bobcat ecology and develop a comprehensive management plan that encompasses preservation of genetic diversity. First, a refined estimate of population density is crucial for modeling and comparison purposes. Second, an assessment of population-habitat interactions is essential to understand how bobcats operate within the human-dominated landscape of Illinois. Third, we must be sure that management strategies include the need to determine if regional populations are distinct, and whether it is possible to identify the region of origin of a bobcat pelt or other products. Finally, outreach and publication of wildlife research are necessary to educate society about resource management; such items provide an effective vehicle to garner public support for wildlife programs.

OBJECTIVES:

1. Estimate population density of bobcats in Illinois south of Interstate 64.
2. Evaluate or develop population models capable of detecting changes in bobcat abundance; provide estimates of input variables (e.g., age- and sex-specific reproduction and survival).
3. Determine population genetics of bobcats in the central United States.
4. Prepare and submit manuscripts for publication in professional journals.

EXECUTIVE SUMMARY

Formerly a state threatened species, bobcats were de-listed by the Illinois Endangered Species Protection Board in 1999. This action opened the possibility of a limited harvest season. Thus the original grant proposal was amended to add a study to compare the genetic characteristics of Illinois bobcats to those from other Midwest states to assist the Department in determining whether conservation of genetic variability is a valid concern within the state and the region. Funds became available during Segments 5, 6, and 7 from those that were originally designated for Job 1.3 (not approved by the U.S. Fish and Wildlife Service). The following Executive Summary highlights important findings from both studies.

Study 1. Status of the Bobcat in Illinois

Job 1.1. Population Density.—The objective is to estimate population density of bobcats in Illinois south of Interstate 64. We used the Penrose distance statistic to model regional habitat similarity to areas within core areas of 52 radiocollared bobcats captured during 1995-99. The core areas were comprised primarily of forest cover (61%). Conversely, the region consisted of a more even mix of agricultural (36%), forest (29%), and grass cover (22%). Mean patch size of forest cover and proportion of forest cover were most correlated ($r \geq 0.39$) to Penrose distance. The Penrose distance model was validated using an independent data set of pinpointed bobcat sighting locations ($n = 248$). Thirty-one percent and 81% of independent bobcat sightings occurred in the top 10% and 25% of distributions of Penrose distances, respectively. We then modeled population density for the region based on Penrose distance, density information from areas occupied by radiocollared bobcats, and bobcat sighting locations. Estimated regional population size was 2,224 bobcats and population density was 0.18 bobcats/km^2.

Job 1.2. Population Modeling.—The objective is to create a spatially explicit population model for bobcats in southern Illinois. We used empirical data from captures, necropsy, and radiotelemetry to provide baseline values for sex- and age-distribution, adult survival, and kitten recruitment. We then created mathematical models and projected population growth and harvest levels of 5%, 15%, and 25% for 5 years into the future. We also estimated potential bobcat harvest based on the number of bobcats accidentally harvested during our radiotelemetry study. The most and least conservative models predicted 8% and 19% growth, respectively. Harvest to maintain current population size based on these values would result in a harvest range between 178 and 423 bobcats/year. However, an even more conservative harvest would be to take the estimated 56 bobcats that are accidentally harvested each year.

Job 1.4. Analysis and Report.—The objective is to summarize information obtained from Jobs 1.1 and 1.2 to provide recommendations for bobcat management in Illinois. We provide recommendations for harvest management and future data collection and research.

Study 2. Population Genetics of Bobcats in the Central United States

Job 2.1. Microsatellite Genotyping.—The objective of this job is to estimate the level of gene flow (migration) among bobcats from 4 central US locations (Illinois, Kansas, Kentucky, and Missouri). We used 5 sets of primers to amplify polymorphic microsatellite loci in 213 bobcats. We found that bobcats throughout the areas we sampled in the south-central US are genetically similar, but that subtle differences in allele frequencies exist. Thus bobcats in the central US do not form a panmictic population, however differences among regional bobcat populations are minor.

Job 2.2. Genotype Analysis.—The objective is to determine whether (1) any of the sample locations harbor unique microsatellite alleles, indicative of reproductive isolation or perhaps subspecific status, and (2) unique microsatellite alleles can be used to diagnose the location of origin of bobcat pelts and other bobcat products. We did not find unique microsatellite alleles from the sample locations. However, we were able to correctly assign origin 60% of the time using only 7 samples and 5 loci. Based on this preliminary finding, we speculate that by using additional polymorphic loci and a restricted set of hypothesis, it should be possible to determine the origin of bobcat pelts and products with high confidence.

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STUDY 1. STATUS OF THE BOBCAT IN ILLINOIS

JOB 1.1: POPULATION DENSITY

Objective: Estimate population density of bobcats in Illinois south of Interstate 64.

A reliable estimate of population density for the southern Illinois region was a necessary precursor to population modeling. The attached manuscript accepted for publication in The Wildlife Society Bulletin (Appendix A) represents the majority of this job. The only additional analysis provided is the overall population estimate based on summing density values for all hexagons (Appendix A), which resulted in a population estimate of 2,224 adult ($\geq$1 yr) bobcats (density = 0.18 bobcats/km^2) for the 13-county region.

This regional density estimate is somewhat smaller than density calculated from home range size and overlap (0.27 bobcats/km^2) on the intensive study area in Jackson and Union counties (Woolf 1999). This is unsurprising given the entire region contains proportionately less highly-suitable bobcat habitat, as primarily influenced by intensive agricultural land use along the Mississippi and Ohio rivers and Saline and Gallatin counties. However, both density estimates are higher than observed in most harvested bobcat populations, which are commonly at densities of 0.05-0.10 bobcats/km^2 (Anderson 1987:11).

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JOB 1.2: POPULATION MODELING

Objective: To create a spatially explicit population model for bobcats in southern Illinois.

We created population models for bobcats in southern Illinois based on empirical data. The attached manuscript (Appendix B) accepted for publication in the Journal of Wildlife

Management describes survival analysis, which constituted a major step toward completion of this job. Although the objective originally included modeling spatial concerns, we did not model in a spatially-explicit context. Given the high level of habitat connectivity in the southern Illinois region (Appendix A) and evidence of long-distance and relatively unimpeded juvenile dispersal (Woolf and Nielsen 1999), the region is best treated as a single management unit with little demographic or spatial variation in bobcat ecology.

INTRODUCTION

Wildlife biologists have created population models for several solitary carnivore species. Models for grizzly bears (*Ursus arctos*, Shaffer 1993) and mountain lions (*Felis concolor*, Beier 1993) have been used for population viability analyses, whereas models for bobcats have been used to predict population responses to harvest (Crowe 1975, Knick 1990). These models were constructed using data from radiocollared or harvested individuals. We created population models for bobcats in southern Illinois using empirical data to provide baseline values for sex- and age-distribution, survival, and recruitment. We then estimated percent population growth and simulated harvest to provide biologists with recommendations for short-term harvest management.

METHODS

We created deterministic population models for the 13 southernmost counties of Illinois (Appendix A) based on demographic values determined from empirical data. Demographic information came from capture data (Woolf and Nielsen 1999) and necropsy data (A. Woolf, unpublished data). Necropsy data consisted of 141 bobcat carcasses collected primarily as road kills during 1995-2001. Sex was determined from examination of external genitalia and age determined from cementum annuli inspection (Crowe 1972).

For simplicity and because habitat quality was similar throughout the entire region (Appendix A), we assumed demographic characteristics were similar throughout southern Illinois. We used 2 methods for modeling bobcat population growth: accounting models and life table analysis. Our goal was to depict several approaches to modeling bobcat population growth and simulating harvest.

Accounting Models

We created accounting models of bobcat population growth in a commercial spreadsheet package. Population growth was modeled according to the following simple equation:

$$N_t - ADMORT + RECR = N_{t+1}$$

where:

N_t = initial adult ($\geq$1 yr) pre-parturition population size at year *t*

ADMORT = annual adult mortality

RECR = kitten recruitment

N_{t+1} = pre-parturition population size at year *t+1*

Initial adult population size (N_t; 2,224 bobcats) was determined from the habitat-relative abundance relationship (Appendix A) and was distributed into adult males and adult females based on proportions from capture data (Woolf and Nielsen 1999). Bobcats were then removed from the population via 1 overall annual mortality rate (ADMORT) from radiotelemetry data (from 1 - pooled annual survival rate, Appendix B). We did not model separate survival rates for males and females or seasonally because no differences in survival existed among these categories (Appendix B). Kitten recruits (RECR) calculated as number of kittens (including those captured in female home ranges that were too small to radiocollar) divided by number of adult females were added and carried over to year N_{t+1} as adults.

Maximum and minimum survival values were chosen based on the standard error of the survival rate (Appendix B). Maximum recruitment values were calculated from capture data. Minimum recruitment values were determined from necropsy data.

We created 2 accounting models based on the aforementioned data. Model 1 was less conservative and consisted of modeling population growth using maximum survival and recruitment rates. Model 2 was more conservative and used minimum survival and recruitment values. We then estimated lambda (λ) as N^{t+1}/N^{t} (Johnson 1994) to depict annual population growth.

Life Table Models

We also modeled population growth based on cohort life table analysis (Caughley and Sinclair 1994, Johnson 1994, Krebs 1994) based on the aforementioned necropsy data. We created a life table similar to Sinclair (1977), who modeled population dynamics of African buffalo (*Syncerus caffer*) from a pick-up sample of skulls afield (Table 1). Males and females were pooled and the life table constructed based on 1-year increments. We extended the approach by Sinclair (1977) by including reproductive estimates and estimating λ (Krebs 1994, Appendix C) given 2 different reproductive estimates; 1 was less conservative (Model 3) and based on maximum recruitment values from capture data, and the other (Model 4) was more conservative and based on minimum recruitment values from the necropsy data.

Harvest Simulations

After predicting population size for Year N_{t+1}, we modeled simulated fall-winter bobcat harvest based on λ for Models 1 and 2, because these represented less conservative and more conservative models, respectively. Harvest was assumed to be completely additive to other mortality causes (Lovallo 2001). We modeled harvest rates of 5%, 15%, and 25% for 5 years into the future, assuming no density-dependent changes in model parameters. We also estimated potential bobcat harvest based on mortality rates of bobcats accidentally taken by licensed trappers presumably seeking harvestable species (Appendix B).

RESULTS

Sex Ratio and Recruitment

We determined sex with certainty for all radiocollared bobcats; 37 of 76 were males; hence, we assumed a 1:1 adult sex ratio. Twenty kittens were captured, but 7 were not radiocollared and sex was unknown. Given that 32 adult females were captured, maximum recruitment was estimated to be 0.62 kittens/adult female (20/32). From the necropsy sample, 26

Table 1. Cohort life table for 141 bobcats collected primarily as roadkills in southern Illinois, 1995-2001. Column headings and calculations are defined in Appendix C.

x	f_x	d_x	l_x	q_x
0	26	0.184	1.000	0.184
1	23	0.163	0.816	0.200
2	17	0.121	0.652	0.185
3	28	0.199	0.532	0.373
4	20	0.142	0.333	0.426
5	9	0.064	0.191	0.333
6	8	0.057	0.128	0.444
7	4	0.028	0.071	0.400
8	3	0.021	0.043	0.500
9	0	---	0.021	---
10	1	0.007	0.021	0.333
11	0	---	0.014	—
12	1	0.007	0.014	0.500
13	1	0.007	0.007	1.000

kittens and 48 adult females were recovered, resulting in a minimum recruitment estimate of 0.54 kittens/adult female. The mean annual mortality rate was 0.16 (Appendix B); based on SE = 0.03 the minimum and maximum mortality rates were 0.13 and 0.19, respectively.

Population Growth and Harvest Simulations

Models 1 and 2 predicted λ to be 1.08 (i.e., annual population growth of 178 bobcats) and 1.18 (i.e., annual population growth of 400 bobcats), respectively. Models 3 and 4 predicted λ to be 1.17 (i.e., annual population growth of 378 bobcats) and 1.19 (i.e., annual population growth of 423 bobcats), respectively. Therefore, depending on which model used, harvest rates of 8-19% would result in stable population sizes.

Simulating harvest levels for 5 years based on λ for Model 1 resulted in increased population size at the 5% harvest level and decreased population sizes at 15% and 25% harvests (Table 2). Harvest rates from Model 2 resulted in increased population size at the 5% and 15% harvests and decreased population size at 25% harvest (Table 2). Based on an accidental harvest rate of 2.5% (Appendix B) and the initial population size, 56 bobcats could be harvested each year to replace those accidentally taken during harvest protection.

DISCUSSION

We created 4 population models based on different modeling techniques and parameter values to provide several projections of bobcat population growth and harvest. Models 1 and 4 predicted 8% and 19% population growth, respectively, indicating relatively close concordance among models. Harvest to maintain current population size based on these values would result in a harvest range between 178 and 423 bobcats/year. The most conservative harvest would be to take the estimated 56 bobcats that are already accidentally harvested each year when protected. Because these bobcats were likely taken incidentally while trappers attempted to harvest other species, we assumed that legal harvest mortality would be completely compensatory. Given we assumed all harvest mortality was completely additive, our models were very cautious because vehicle-related mortality rates would likely decline somewhat if harvest was implemented.

Table 2. Harvest simulations for bobcats in southern Illinois based on harvest rates applied to 2 deterministic accounting models following 5 years of population growth.

Harvest rate	Model 1	Model 2
5% harvest		
% change[a]	+14	+77
n bobcats[b]	2,731	4,646
15% harvest		
% change	-35	+2
n bobcats	1,566	2,664
25% harvest		
% change	-65	-46
n bobcats	837	1,425

[a]Percentage change in bobcat population following harvest.
[b]Number of bobcats remaining in the population following harvest.

Potential harvest rates for bobcats in southern Illinois are within the range of those used in other states. In a hypothetical bobcat population model, Knick (1990) recommended a maximum sustained yield of 20-25%. South Dakota, Wisconsin, and Pennsylvania use harvest rates of 10-15% (Fredrickson and Rice 1996), 10% (Rolley et al. 2001), and <5% (Lovallo 2001), respectively. Modeling indicates that bobcat populations in southern Illinois are growing at least as fast as populations in these states, which is expected given high survival rates and very suitable habitat conditions.

Bobcat survival estimates from radiotelemetry data were robust with a known level of error; however, recruitment rates contained unknown accuracy or error. When estimated via life table analysis or from capture data, bobcat recruitment is very difficult to quantify. Life table analysis commonly underestimates the age-0 class (Johnson 1994:437). Further, neonatal kitten capture is difficult, so direct estimates of recruitment via radiotelemetry are improbable. Regardless, methods we used indicated some concordance, as recruitment estimates differed by only 13%.

Recruitment rates for bobcats in southern Illinois (0.54 minimum and 0.62 maximum) were high relative to most studies (Crowe 1975, Fritts and Sealander 1978, Rolley 1985). This phenomenon may be explained in 2 ways. First, recruitment is thought to be dictated by prey densities (Rolley 1985) and prey densities in southern Illinois may have been relatively higher than on other study areas (e.g., desert environments [Lembeck and Gould 1979] or mature forests [Berg 1979]). Second, methodological differences in calculating recruitment may have resulted in other studies underestimating recruitment, because these studies used life tables alone and not capture data.

The reliability of life table analysis depends on how the data meets the following assumptions (Caughley and Sinclair 1994:45): (1) the sample is an unbiased representation of the living population, (2) age-specific mortality and reproduction must remain essentially the same over time, and (3) rate of increase must be close to zero. We believe the age-distribution of the sample was not terribly biased because all bobcats were equally likely to be hit by vehicles, except perhaps the age-0 class that would not be as motile as adults. Assumptions 2 and 3 were likely violated somewhat, as the population likely grew over the 6-year period of data collection. Thus, the most defendable models may be the accounting models (Models 1 and 2). These models were very straightforward, contained few parameters, and in general were more conservative than the life table models.

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JOB 1.4: ANALYSIS AND REPORT

Objectives: (1) Provide recommendations to improve management of the bobcat in Illinois, and (2) prepare and submit manuscripts for publication in professional journals.

INTRODUCTION

Bobcats in the United States are protected by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) which requires that prior to pelt export, states must prove that harvest will not be detrimental to survival of the species (Gluesing et al. 1986). Minimum requirements for biological information prior to evaluating whether harvest would be detrimental include (1) population trends, (2) total harvest and harvest distribution information, and (3) habitat evaluation (Mech 1978, Gluesing et al. 1986). Data from Jobs 1.1 and 1.2, in conjunction with the initial phase of this study (Woolf and Nielsen 1999), provide this information. We also present suggestions regarding necessary management information required by CITES (Mech 1978, Gluesing et al.1986) and additional recommendations to improve management of bobcats in Illinois.

METHODS

Methods and results obtained from Jobs 1.1 and 1.2 were the basis for all quarterly, annual, and final project reports and the discussion and recommendations listed below.

DISCUSSION

Bobcats were delisted as a state-threatened species in Illinois in 1999, following evaluation of sighting data and initial habitat analysis that indicated bobcat populations were secure statewide (Bluett et al. 2001). Based on all available indicators from this study, bobcats in the southern Illinois region could sustain a limited, well-regulated harvest. Bobcats are in excellent physical condition (A. Woolf, unpublished data) and have high survival rates. Density is high relative to most harvested populations. Habitat suitability is excellent throughout most of the region. Hence, populations have grown substantially since harvest protection and our models indicate a still-increasing population.

Pennsylvania provides the best model for initiating a bobcat harvest following 30 years of harvest protection. After several years of data collection similar to Illinois (e.g., habitat and population modeling), the Pennsylvania Game Commission (PGC) instituted a bobcat harvest using a permit-based quota system during the 2001-2002 furbearer season (Lovallo 2001). The PGC allocated 290 permits (randomly chosen via public drawing from 3,300 applicants) to achieve a potential harvest goal of 175 bobcats (assuming a 60% success rate). Applicants submitted a 1-time fee of $5 and were required to purchase a state furbearer permit if drawn. The seasonal bag limit was set at 1 bobcat/permit, and harvest was concurrent with the normal furbearer season (mid-Oct to mid-Feb). During the first season, Pennsylvania trappers and hunters harvested only 58 bobcats, indicating a success rate of 20% (M. Lovallo, Pennsylvania Game Commission, personal communication). Hence, the approach taken by PGC was much more conservative than planned.

Our habitat analyses were intended to determine if there were important habitat factors for bobcats that needed protection or management. At a statewide scale, forest cover is clearly important to bobcats; and forested areas in Illinois can be used as the basis for management subunits (Woolf et al. 2002). Analyses presented here indicate that no truly critical habitats exist at the southern Illinois regional scale, or for individual bobcats (Nielsen 2000, Kolowski 2000). Therefore, we conclude that because bobcats have fared exceedingly well in the absence of targeted management, and there is no evidence of special habitat needs, extensive efforts at protecting habitat for bobcats in Illinois is not necessary.

RECOMMENDATIONS

- Evidence is clear that bobcats in the southern Illinois region could withstand a controlled, limited harvest without risk to the population. If such a harvest is planned, we recommend a harvest of $\leq$200 individuals based on our modeling. Similar to Pennsylvania (Lovallo 2001), permits should be allocated via lottery and harvest conducted during the normal furbearer season.
- Harvests should be carefully monitored and based on annually updated models. Also, all pelts should be marked and registered. These actions would ensure conformity to CITES regulations for bobcat management (Mech 1978, Gluesing et al. 1986).
- Ideally, all carcasses should be submitted to designated biologists to collect body weights, sex, lower canines (for cementum annuli analysis), and reproductive tracts. These data are vital to monitor age, condition, and reproduction; and detect any changes in these population parameters.
- Continue collection of bobcat sightings from successful deer hunters at deer check stations and the archery survey as previously reported (Woolf and Nielsen 1999). Such data provide a valuable indication of long-term trends in statewide populations.
- Although the population ecology of the bobcat is well understood in Illinois and suffices as a foundation of science-based management of the species, important research questions remain unanswered. We suggest the following research topics be considered for funding in future years:

- A study (radiotelemetry) of bobcat kitten recruitment to acquire data that will allow refinement of population models (recruitment in current models was calculated with unknown error).

- Study of human attitudes towards bobcats (e.g., Harrison 1998) and bobcat harvest. Such human dimensions studies are increasingly important because of public opposition to furbearer management (Batcheller et al. 2000, Rolley et al. 2001).

- Increased competition with sympatric furbearers (e.g., coyotes and foxes) is probable. Therefore, we recommend a concurrent study of these species to determine competitive interactions.

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PUBLICATIONS

Several manuscripts were published in professional journals during this project. We also hosted a national symposium on bobcat ecology and management at The Wildlife Society 2000 Conference in September, and edited the proceedings. Also, we are preparing a semi-technical bulletin for publication by the Illinois Department of Natural Resources, Division of Wildlife Resources that summarizes knowledge of the ecology of the bobcat in Illinois and documents research findings not published in professional journals. Preparation of this final report constitutes the remainder of activity for this job. Publications accepted or in print are listed as follows:

Kolowski, J. M., and A. Woolf. 2002. Microhabitat use by bobcats in southern Illinois. Journal of Wildlife Management: *in press*

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STUDY 2. POPULATION GENETICS OF BOBCATS IN THE CENTRAL UNITED STATES

JOB 2.1: MICROSATELLITE GENOTYPING

Objective: Estimate the level of gene flow (migration) among bobcats from 4 central US locations (Illinois, Kansas, Kentucky, and Missouri).

JOB 2.2: GENOTYPE ANALYSIS

Objectives: Determine whether (1) any of the sample locations harbor unique microsatellite alleles, indicative of reproductive isolation or perhaps subspecific status, and (2) unique microsatellite alleles can be used to diagnose the location of origin of bobcat pelts and other bobcat products.

The objectives of Jobs 2.1 and 2.2 were collectively studied and reported by Bowles et al. (submitted) in a draft manuscript (Appendix D) appended to this final report. Following is the abstract of the submitted manuscript.:

Five polymorphic DNA microsatellite loci were used to evaluate the genetic structure of bobcat populations in Illinois, Kansas, Kentucky, Louisiana, and Missouri, to determine levels of gene flow among locations and whether microsatellite loci might be used to identify the origin of bobcat pelts and products. Five sets of primers previously developed for domestic cat successfully amplified polymorphic microsatellite loci in 213 bobcats. Variation was high; each locus exhibited between 7 and 11 alleles and observed heterozygosities ranged from 0.308 to 0.846. There were few significant departures from Hardy-Weinberg equilibrium, although one locus (Fca 90) exhibited significant heterozygote deficiencies in 3 of 7 geographic samples. The overall F_{ST} value was 0.043 and highly significant (P<0.0001), indicating that bobcats in the central US do not constitute a single panmictic population. A Mantel test for the relationship between geographic and genetic distance was not significant, indicating a poor relationship between genetic and geographic distance. A neighbor joining dendogram indicated that there was little phylogeographic signal among the data. Assignment tests correctly placed 60% of all bobcats within the correct sample (out of 7) indicating that the use of additional loci microsatellites may be useful to reliably identify the origin for bobcat pelts and products.

JOB 2.3: ANALYSIS AND REPORT

Objectives: (1) To provide recommendations to incorporate knowledge of genetics in management of the bobcat in Illinois, and (2) prepare and submit manuscripts for publication in professional journals.

This job has been accomplished with this final performance report and the appended manuscript (Appendix D).

LITERATURE CITED

Bowles, J. R., A. Woolf, and W. J. Heist. Genetic population structure and population assignment in bobcat (*Lynx rufus*) from the central United States determined by analysis of microsatellite loci.

APPENDIX A.

APPENDIX B.

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SURVIVAL OF UNEXPLOITED BOBCATS IN SOUTHERN ILLINOIS

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Abstract: Knowledge of survival rates is integral to understanding factors influencing population dynamics. Although bobcat (*Lynx rufus*) survival has been quantified throughout most of its range, there have been few studies of unexploited populations and of populations in areas of high road and human density. Therefore, we estimated annual and seasonal survival rates and cause-specific mortality for 75 bobcats (39 F, 36 M) in southern Illinois during 1995–2000. Annual survival rates (M = 0.823, F = 0.857) were similar between sexes ($P = 0.580$). Seasonal survival rates ranged from 0.869–0.948 and were similar among seasons and sexes ($P = 0.412$). Pooled estimates of annual and seasonal survival ranged from 0.839–0.938 and were among the highest reported for bobcats. When seasonal mortality agents occurred for both sexes, rates of seasonal cause-specific mortality ranged from 0.016–0.081 and did not differ between sexes ($P \geq 0.317$). Most mortalities were human-caused, and vehicle-caused mortality rates were the highest reported for bobcats. Although human influence currently is not severely limiting bobcat populations in southern Illinois, continued human expansion into rural areas may adversely affect bobcats.

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Key words: bobcat, cause-specific mortality, *Lynx rufus*, southern Illinois, survival, unexploited population.

Bobcat (*Lynx rufus*) survival rates and causes of mortality have been quantified throughout most of North America (McCord and Cardoza 1982, Anderson 1987). Such studies have provided wildlife managers with data necessary for population modeling and an understanding of factors limiting population growth (Berg 1979, Hamilton 1982, Knick 1990). Despite the abundance of survival information for bobcats, knowledge is incomplete in several areas. First, bobcat survival has primarily been studied in relatively undeveloped, publicly-owned, or protected settings (e.g., Bailey 1974, Fuller et al. 1985). Therefore, little is known regarding bobcat survival in areas containing relatively high human and road densities. In such instances, vehicle-caused mortality may appreciably limit population growth. Second, bobcat survival has primarily been studied for harvested populations or on protected populations within states open to bobcat harvest (Bailey 1974, Lembeck and Gould 1979, Knick 1990, Chamberlain et al. 1999). However, little bobcat research has been conducted within states entirely closed to harvest.

Southern Illinois provided a unique setting to study bobcat survival and cause-specific mortality in a rural landscape dominated by humans. Since 1971, bobcats in southern Illinois have been protected from harvest (Woolf et al. 2000), and are isolated from other states that harvest bobcats via distance (i.e., Wisconsin) and large rivers (i.e., the Ohio and Mississippi Rivers). Our objectives were to (1) estimate annual and seasonal survival and cause-specific mortality rates for male and female bobcats, and (2) evaluate differences in annual and seasonal survival rates and seasonal differences in cause-specific mortality rates between male and female bobcats.

STUDY AREA

Bobcats were trapped on 2 study areas (eastern study area: 1,000 km^2; western study area: 791 km^2) in the 16 southernmost counties of Illinois (Woolf and Nielsen 1999). This region included the Shawnee Hills, Ozark, Lower Mississippi River Bottomlands, and Coastal Plain physiographic regions (Neely and Heister 1987). Land cover of the eastern study area consisted primarily of closed-canopy mixed hardwood forests (55%; mostly white oak [*Quercus alba*], black oak [*Q. rubra*] and hickory spp. [*Carya* spp.]); rural grasslands (26%); and cropland (11%; mostly corn and soybeans [Luman et al. 1996]). Land cover of the western study area consisted of forests (46%), rural grassland (8%) and cropland (28%) with a similar species composition to the eastern study area. Streams were abundant on the landscape (stream density = 1.1 km/km^2). Elevation ranged from 92–316 m, with a mean slope of 1.4°. Human population density on the eastern and western study areas was 17.8 and 6.4 persons/km^2, respectively. Road densities were 1.4 and 1.1 km/km^2 for the eastern and western study areas, respectively.

METHODS

Trapping and Radiotelemetry

During November–March 1995–99, we captured bobcats with either cage-type traps constructed of galvanized wire mesh (38 x 38 cm x 90 cm) or padded number 3 Soft-catch® (Woodstream Co., Lititz, Pennsylvania, USA) foot-hold traps. We chemically immobilized captured bobcats for handling with a 9:1 combination of ketamine hydrochloride and xylazine hydrochloride (both 100 mg/mL concentration solution). We did not use a reversal drug following handling. We administered drugs intramuscularly at a target dosage of 13 mg/kg estimated body mass. We sexed, weighed, and classified bobcats as adults (≥1 yr) or juveniles based on mass (bobcats <5 kg were considered juveniles), and condition of dentition. Capture and handling procedures were approved by an Institutional Animal Care and Use Committee at Southern Illinois University at Carbondale (Animal Assurance #A-3078-01) and under provisions of Illinois Endangered Species Permit #95-14S.

We fitted adult bobcats with Telonics (Mesa, Arizona, USA) model 315-S6A and Wildlife Materials (Carbondale, Illinois, USA) model HLPM-2140M radiocollars equipped with mortality sensors. We used standard ground and aerial radiotelemetry techniques (White and Garrott 1990) to locate bobcats 2 or 3 times/week. We used a TS-1 scanner (Telonics, Mesa, Arizona, USA), hand-held 2- or 3-element yagi antennas, and compass for ground tracking. We used 2-element yagi antennas mounted on the wing struts of a Cessna 172 aircraft or on the skid of a Bell Long Ranger II helicopter for aerial telemetry. Upon receiving a mortality signal, we located and recovered dead bobcats to determine cause of mortality. Dead bobcats were transported to Southern Illinois University at Carbondale for necropsy. We classified mortalities into 4 categories based on field observations and necropsy information: vehicle-caused (i.e., automobiles and trains), accidental harvest (i.e., trapping), natural, or unknown.

Survival and Cause-specific Mortality

We estimated annual and seasonal survival rates and cause-specific mortality of adult bobcats using number of transmitter-days (Trent and Rongstad 1974, Heisey and Fuller 1985*a*) in the Program MICROMORT (Heisey and Fuller 1985*b*). We defined seasons by dividing the year into 2 biologically meaningful periods that approximated changes in phenology and bobcat reproductive events. We defined the breeding-gestation period as 1 November–30 April, which approximated back-dated conception dates from bobcats litters observed in the field. We defined the parturition-kitten-rearing period as 1 May–31 October.

We censored bobcats from analysis when radiocollars were lost or failed and pooled data over study years by sex. We used chi-square tests in Program CONTRAST (Hines and Sauer 1989, Sauer and Williams 1989) to test for differences ($\alpha = 0.05$) in annual and seasonal survival rates between males and females. We maintained experiment-wise error rate during multiple comparisons by adjusting α with a Bonferroni correction factor (α/no. of comparisons, Neter and Wasserman 1974). When seasonal mortality agents occurred for both sexes, we also tested for seasonal differences in cause-specific rates between males and females. We then estimated pooled annual and seasonal survival rates for all bobcats when sex-specific rates were similar.

RESULTS

During 22 November 1995–18 October 2000, 75 adult bobcats (39 F, 36 M) monitored for 39,714 radiodays ($\bar{x}$ days/bobcat = 529.5 $\pm$ 37.3 [SE], range 21–1,700) were used for survival analysis. Nineteen mortalities (11 M, 8 F) occurred during the study; of these 10 (52%) were hit by automobiles, 3 (16%) were unknown, 2 (11%) were hit by trains, 3 (16%) were accidentally trapped, and 1 (5%) was natural (cachexia resulting from stomach obstruction). No bobcats died from capture myopathy. Most mortalities ($n = 12$, 63%) occurred during the breeding-gestation season; the others ($n = 7$, 37%) occurred during the parturition-kitten-rearing season.

Annual survival rates of males and females (Table 1) were similar ($\chi^2_1 = 0.30$, $P = 0.580$). Seasonal survival rates ranged from 0.869–0.948 (Table 1) and were similar among seasons and sexes ($\chi^2_3 = 2.87$, $P = 0.412$). Pooled estimates of annual and seasonal survival ranged from 0.839–0.938 (Table 1).

No bobcat mortalities of unknown causes occurred during the breeding-gestation season and no natural mortalities or accidental harvest occurred during the parturition-kitten-rearing season (Table 2). No females died from natural causes during any season. When seasonal mortality agents affected both sexes, rates of seasonal cause-specific mortality ranged from 0.016– 0.081 (Table 2) and did not differ ($0.08 \leq \chi^2_1 \leq 1.00$, $0.317 \leq P \leq 0.765$) between sexes for any mortality agent. Pooled male and female cause-specific mortality rates were 0.101 (SE = 0.028), 0.008 (SE = 0.008), 0.025 (SE = 0.014), and 0.025 (SE = 0.014) for vehicle-caused, natural, accidental harvest, and unknown causes, respectively.

DISCUSSION

Survival rates for bobcats vary considerably across their range. Annual survival rates of harvested populations are often <70% (e.g., 19 and 61% on 2 separate Minnesota study areas [Fuller et al. 1985] and 56-66% in Oklahoma [Rolley 1985]), but survival of unexploited populations is generally higher (Bailey 1974, Lembeck and Gould 1979, Knick 1990, Chamberlain et al. 1999). However, the previously studied unexploited populations represented smaller study areas within states where bobcats are harvested; thus, the results were affected by harvests outside of the study area. Indeed, Bailey (1974) reported that 7 of 20 (35%) mortalities occurred by harvest of tagged individuals that had moved outside his study area. Therefore, we provide the first survival analysis of bobcats that were protected statewide and isolated from harvested populations.

Generally, human activities are the primary cause of mortality in bobcat populations (Bailey 1974, Berg 1979, Hamilton 1982). Legal harvest is responsible for a high proportion of deaths in exploited populations (Rolley 1985, Litvaitis et al. 1987, Lovallo 1993) and incidental or illegal harvest can appreciably limit unexploited populations (Knick 1990, Chamberlain et al. 1999). Further, mortalities from vehicle collisions have been reported, but these generally comprise <20% of the mortalities (Knick 1990, Chamberlain et al. 1999).

During our study, human activities were the primary cause of mortality, resulting in 15 of 19 (79%) diagnosed deaths and an annual mortality rate of approximately 13%. In addition, we documented the highest reported rates of vehicle-caused mortalities for bobcats. We believe the relatively high road density (1.4 km/km^2) in southern Illinois is responsible for the high rate of vehicle-caused mortalities we observed. Although not usually reported, other study areas appear to have much lower road densities (e.g., Lovallo and Anderson [1996:73] report road densities of 0.14-0.56 km/km^2). Compared to other unharvested populations (Lembeck and Gould 1979, Knick 1990, Chamberlain et al. 1999), we detected a lower rate of mortality from incidental or illegal harvest. This may be attributable to fewer licensed trappers operating in Illinois (Woolf and Hubert 1998) relative to studies conducted in other states.

Despite high road densities and human populations, annual survival rates for unexploited bobcats in southern Illinois were among the highest reported in the scientific literature (Fuller et al. 1995, Chamberlain et al. 1999). This is likely due to the relatively low incidence of accidental harvest and natural mortality. We diagnosed only 1 natural mortality; cachexia due to stomach obstruction from a large hair ball. Further, a separate data set of southern Illinois bobcat necropsies (A. Woolf, unpublished data) confirmed that debility due to either infectious disease or malnutrition was uncommon. Of 118 bobcats >1 yr old killed in vehicular collisions, 116 (>98%) were in good or excellent physical condition as indicated by high fat reserves. Of the 2 in poor condition, infectious disease was not evident.

Several studies have quantified sex- and season-specific differences in bobcat survival (Knick 1990, Chamberlain et al. 1999). Annual survival is often lower for males than females in exploited populations (Fuller et al. 1985, Litvaitis et al. 1987). This is attributed to males being more vulnerable to harvest because of their increased movements (Anderson 1987:20), although this explanation may not be accurate in all situations (McCord and Cardoza 1982, Chamberlain et al. 1999). However, as in other unexploited populations (Knick 1990), we detected no differences in survival between males and females.

Studies of harvested and unharvested populations have provided mixed results regarding differences in sex-specific seasonal survival rates. Fuller et al. (1985) determined that fall-winter survival rates of males were lower than females. However, unharvested bobcats exhibited no differences in sex-specific seasonal survival (Knick 1990). Similar to Knick (1990), but contrary to Chamberlain et al. (1999), no differences in seasonal survival between males and females were evident in our study. Chamberlain et al. (1999) suggested that low summer survival of females versus males may have been due to increased energetic demands of parturition and young-rearing, whereas males do not have these energetic demands. Specifically, they indicated that kitten-rearing females exhibited greater movement rates and diel activity during these periods than others. However, female bobcats in southern Illinois exhibited no seasonal differences in movement or activity rates (Kennedy 1999). Additionally, no differences in cause-specific mortality rates between males and females were detected in our study, suggesting similarities in mortality factors between the sexes.

Following Fuller et al. (1985), we pooled data from several years to estimate survival rates for bobcats. We believed this was appropriate because the study was conducted over a relatively short temporal scale and low annual sample sizes would have resulted in low statistical power. Further, we believe our estimates of annual survival would have been biased by differing numbers of radiodays each year. For example, we monitored bobcats for >9,600 radiodays/year during 1997-99, whereas bobcats were monitored for <4,900 radiodays each year in 1996 and 2000. With these differences in radiodays, it was possible that more mortalities could have occurred in years when more monitoring occurred. Thus, we concluded that testing for differences in annual survival rates was unfounded and biologically meaningless (Yoccoz 1991, Cherry 1998).

MANAGEMENT IMPLICATIONS

Bobcats in southern Illinois survive at levels among the highest reported, which contributed to a high population density (0.27 bobcats/km^2, Nielsen and Woolf 2001) relative to harvested populations (0.05-0.10 bobcats/km^2, Anderson 1987:11). This indicates that although a landscape contains relatively high densities of roads and humans, bobcats can exist at high densities given a relatively stable environment, plentiful prey resources, and highly suitable habitat (Nielsen 2000). Currently, human influence is not severely limiting bobcat populations in southern Illinois, however, there is concern given increasing trends in rural development. Between 1980 and 1995, human population growth in the United States was approximately 16% (Frey and Johnson 1998:95), and population growth in rural areas during the 1990s (5.1%) almost doubled that of the 1980s (2.7%). If humans continue to populate rural areas, bobcat populations in southern Illinois may be adversely affected by increased vehicle kills, other accidental mortalities, and decreasing public acceptance of high bobcat populations.

In addition to providing demographic information specific to bobcats in Illinois, our results may be useful to wildlife managers in other states. For example, bobcat harvest is prohibited in the Midwest states of Iowa, Indiana, and Ohio (Woolf and Hubert 1998). Managers in these states could use our survival rates for population modeling or population viability analysis, provided there are similarities in road densities and habitat quality.

Further, survival rates for bobcats in southern Illinois could provide a maximum value for stochastic modeling of bobcat survival in any landscape.

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Table 1. Annual and seasonal survival rates (*S*) for bobcats in southern Illinois, November 1995–October 2000.

Season	Radiodays	Mortalities	*S*	SE
Males				
Parturition[a]	10,244	3	0.948	0.029
Breeding[b]	10,393	8	0.869	0.042
Annual	20,637	11	0.823	0.042
Females				
Parturition	9,754	4	0.910	0.037
Breeding	9,203	4	0.942	0.031
Annual	18,957	8	0.857	0.045
Pooled				
Parturition	19,998	7	0.938	0.022
Breeding	19,596	12	0.894	0.028
Annual	39,595	19	0.839	0.031

[a] 1 May–31 October.

[b] 1 November–30 April.

Table 2. Seasonal cause-specific mortality rates (*M*) for male and female bobcats in southern Illinois, November 1995–October 2000.

		Males			Females		
Season	Mortality cause	Mortalities	*M*	SE	Mortalities	*M*	SE
Breeding[a]	Vehicle	5	0.081	0.035	2	0.038	0.026
	Natural	1	0.016	0.016	0	0.000	0.000
	Accidental harvest	2	0.032	0.023	1	0.019	0.019
	Unknown	0	0.000	0.000	0	0.000	0.000
Parturition[b]	Vehicle	2	0.034	0.024	3	0.053	0.030
	Natural	0	0.000	0.000	0	0.000	0.000
	Accidental harvest	0	0.000	0.000	0	0.000	0.000
	Unknown	1	0.017	0.017	2	0.035	0.025

Table 2. Continued.

		Males			Females		
Season	Mortality cause	Mortalities	*M*	SE	Mortalities	*M*	SE
Pooled over seasons	Vehicle	7	0.110	0.039	5	0.088	0.037
	Natural	1	0.015	0.015	0	0.000	0.000
	Accidental harvest	2	0.030	0.021	1	0.017	0.017
	Unknown	1	0.017	0.017	2	0.035	0.025

[a] 1 May–31 October.

[b] 1 November–30 April.

APPENDIX C.

Appendix C. Equations for life table analysis based on 141 bobcats collected primarily as roadkills in southern Illinois, 1995-2001. The cohort life table analysis was based on the following equations taken from Sinclair (1977) and Krebs (1994:168-189).

x = age-class

f_x = mortality frequency from pick-up sample

d_x = proportion dying during age-interval = f_x/total bobcats in sample

l_x = proportion surviving to that age-interval = $l_x - d_x$

q_x = age-specific mortality rates = d_x/l_x

b_x = age-specific natality rates

R_0 = net reproductive rate = $\sum l_x/b_x$

G = mean length of a generation = $\sum l_x/b_x x/R_0$

r = intrinsic capacity for increase, approximated according to Krebs (1994:181)

$\lambda = e^r$ = lambda, the finite rate of increase

APPENDIX D.