EFFECTS OF REMOVAL ON SPATIAL ORGANIZATION AND HABITAT USE OF BOBCATS

by

GREG LYNCH

(Under the Direction of Under the Direction of Robert J. Warren)

ABSTRACT

This study investigated bobcat (*Lynx rufus*) spatial organization and habitat use relative to a known decrease in population resulting from an experimental removal. After an approximately 50% reduction in abundance, male bobcats shifted ($F_{1,3}$=138.08, P= 0.0013) their home ranges when surrounding bobcats were removed. Dispersion of animal locations increased less as a function of removal for female bobcats that were exposed to the removal of a male ($F_{1,14}$=6.78, P=0.0209), or both a male and female ($F_{1,14}$=8.27, P=0.0122) than for control animals. Male bobcats may have shifted their home ranges to gain access to more breeding opportunities. The decrease in dispersion of female locations may be the result of a decrease in intraspecific competition or possibly the result of less detailed maintenance or inspection of scent markings along the boundary of a bobcat's territory. Neither habitat selection nor habitat use differed as a function of removal in this study, suggesting that density-dependent habitat selection was not occurring.

INDEX WORDS: Bobcat, dispersion, habitat use, *Lynx rufus*, removal, shift, spatial organization

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GREG LYNCH

B.S., Clemson University, 2003

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2005

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GREG LYNCH

Major Professor: Robert J. Warren

Committee: Mike L. Conner
Steven B. Castleberry
Ronald L. Hendrick

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
December 2005

ACKNOWLEDGEMENTS

I want to first and foremost thank God in heaven for blessing myself and my family and for giving us the ability to follow our dreams. Without help from my family, and especially my wife Windsor, I may have never gotten the inspiration to accomplish my goals. Thanks to William for coming along at just the right time to end one portion of our lives and to begin another. I would also like to thank little Bea for always having a "smile" on her face and being there to cheer us up no matter how stressful the day was.

An incredible amount of thanks must be given to Dr. Mike Conner and Dr. Bob Warren for giving me the opportunity to pursue my dreams. Both of you have been more of a mentor to me than you will ever know. Thanks also to my committee members Dr. Steven Castleberry and Dr. Ronald Hendrick for taking time out of your busy schedules to review papers and attend meetings and to all of the teachers and friends that have helped mold me into the person that I am.

Thank you to the staff at the Joseph W. Jones Ecological Research Center, and The University of Georgia. The resources provided made my experience here second to none. I can't even begin to list the names of persons, who without their help this would all have not been possible. I am a Coca Cola man for life!! Special thanks to the wildlife lab and especially Daniel Temple and Danny Gammons for helping me with trapping and last, but not least, I would like to thank the many friends that we made while at Ichauway. It will be truly difficult to leave this place and all of the wonderful people.

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CHAPTER 1

INTRODUCTION, LITERATURE REVIEW, JUSTIFICATION, OBJECTIVES, AND THESIS FORMAT

INTRODUCTION

Bobcat home ranges and spatial organization are thought to be controlled by numerous factors including prey abundance, habitat quality, breeding opportunities, den sites, and time in residence (Bailey 1974, Griffith and Fendley 1986, Clutton-Brock 1989, Conner et al. 1999). The factors that promote a solitary life are thought to be prey size and hunting mode. Smaller carnivores such as bobcats can easily kill prey smaller than themselves and have no need for cooperative hunting. The existence of conspecifics in a bobcat's immediate surroundings should theoretically have a negative effect on foraging efficiency by disturbing prey or depleting resources (Sandell 1989).

Bailey (1974) suggested that scarce prey or harsh weather may modify spatial organization, with bobcats tolerating more or less overlap depending on the pressures of the local environment. As bobcats adjust to changing environments, home range sizes and spatial organization may change fluidly when scarce resources are shared.

Benson et al. (2004) used a long-term telemetry data set to study reoccupation of home ranges following the death of a resident bobcat. They found 10 cases in which another bobcat assumed use of a vacated area after the death of a resident individual. Anderson (1988) removed a resident male bobcat and noted an overlapping resident male started using the vacated area within 6 days. Two other studies noted a range shift by neighboring individuals following the death of a resident bobcat (Bailey 1974, Litvaitis et al. 1987).

Presumably it would be beneficial in terms of breeding opportunities or prey availability for a bobcat to change its area of use (Lovallo and Anderson 1995). While home ranges and core areas of bobcats are generally exclusive, bobcats may investigate areas outside of their areas of use and be aware of resources in adjacent bobcats' home ranges, thereby allowing them to adjust to changes in spatial organization within the population (Lovallo and Anderson 1995, Benson et al. 2004).

Home Range

Various factors influence bobcat home range sizes throughout their range. It appears that home range size is inversely proportional to prey abundance. Berg (1979) found that male home ranges averaged 62 km^2 in Minnesota, whereas male home ranges in Alabama averaged 2.6 km^2 (Miller and Speake 1979). The differences in home range sizes from northern to southern latitudes may be the result of higher net prey productivity in the southern range of the bobcat's distribution (Bailey 1974). Bobcat home range size also may be influenced by seasonal climatic and ecological changes. In the Southeast, Fendley and Buie (1986) found the longest movements during winter and the shortest movements during summer, presumably in response to greater prey abundance during the warmer months. Conversely, Bailey (1974) found that bobcats in southeastern Idaho showed a decline in activity during winter months and suggested this may be in response to the difficulty bobcats encountered when traveling in deep snow. Although home ranges appear to be more closely linked to habitat quality and prey abundance, other factors, such as energetic demands, availability of escape cover, hunting cover, den sites, and the numbers of mating opportunities, also influence home range size, abundance and distribution (Anderson 1987).

Bailey (1974) suggested that bobcats may establish home ranges by prior rights, meaning that the home range is acquired on a "first come, first serve" basis. During Bailey's study, no transient or neighboring resident appeared to settle in a home range permanently occupied by a resident. Permanent home ranges were occupied only following a resident's death.

Home range also may be affected by the bobcat's time-in-residence (Conner et al. 1999). Over time, male bobcats may increase their home range size and expand breeding opportunities, thereby increasing their overall fitness. A female's time-in-residence is thought to improve hunting success within the home range, increasing hunting efficiency, and resulting in decreased home range size (Conner et al. 1999). In the same context, time-in-residence may affect the animals' familiarity with the surrounding landscape and allow the animal to move to and from needed resources more efficiently (Goodenough et al. 1993).

Male bobcat home ranges are generally larger than female home ranges (Bailey 1974, McCord and Cardoza 1982, Knowles 1985, Fendley and Buie 1986, Knick 1990, Conner et at. 1992). Male home ranges are largest during the breeding season, whereas female ranges are smallest at this time because of denning activities and rearing kittens (Bailey 1974, Anderson 1987, Litvaitis et al. 1987, Sandell 1989). Male bobcat home range size is assumed to be largely dependent on available mating opportunities, while female home range is closely linked to availability of resources (Sandell 1989). Nielson and Woolf (2001) suggested that males may not need to enlarge home range sizes during the breeding season because of a relatively high abundance of females.

While bobcats maintain territories, home ranges are not necessarily defended from conspecifics. Adult bobcats mark their territory with feces, urine, scrapes, and anal gland secretions (Bailey 1974). Core areas, where the animal spends most of its time, may represent areas of more aggressive territoriality (Chamberlain and Leopold 2001, Nielson and Woolf 2001). Nielson and Woolf (2001) suggested that core areas benefit bobcats by providing exclusive denning sites for females and breeding areas for males. Male home range areas may correspond to female core areas during the breeding season, providing increased breeding opportunities (Chamberlain and Leopold 2001). Nielson and Woolf (2001), as well as Chamberlain and Leopold (2001), reported that while intrasexual home range overlap was extensive, most core areas remained nearly exclusive.

Conner et al. (1992) suggested that larger bobcat home ranges may be the result of poor habitat quality because preferred habitats were the least available on their study area. Fendley and Buie (1986) reported that home range sizes increased substantially from previous studies in the 1960's, presumably because of an increase in planted pine plantations and a corresponding decrease in early successional habitats leading to decreasing small mammal populations.

Habitat Use

Bobcats are found in a wide variety of habitats from the coastal swamps of the Southeast to the arid deserts of the Southwest, and from northern boreal forests to the humid tropical regions of Mexico (Anderson 1987). Specific habitats include, but are not limited to, boreal coniferous and mixed forests in the North, bottomland hardwood forest, old-field and coastal swamp in the Southeast, and desert and scrubland in the Southwest. Only large tracts with intensively cultivated areas appear to be unsuitable habitat (Rollings 1945, Hall and Newsom 1976, Knowles 1985, Lovallo and Anderson 1996, Anderson 1987, Chamberlain et al. 1998).

Prey abundance, protection from severe weather, availability of rest areas, dense cover, and freedom from disturbance are key factors in bobcat habitat use (Anderson 1987). Dense cover is particularly important for the bobcat to efficiently utilize stalking and ambush hunting techniques (Rolley 1987). The influence of habitat quality on prey abundance and stability suggests that quality prey habitat may be a limiting factor in bobcat populations (Anderson 1987, Rucker et al. 1989). Dense cover types that support high concentrations of prey species may provide food as well as optimal ambush hunting conditions (Knowles 1985).

Spatial Organization

Bobcats are solitary animals that have limited interaction with other individuals in the population (Sandell 1989). Bobcats may be separated into 3 general age classes: residents, transients, and kittens. Breeding-age bobcats that have established areas of use are considered residents, whereas transients are generally dispersing juveniles that coexist with residents as a floating population. Kittens are individuals that are largely dependent on the female and have not dispersed (Bailey 1974, McCord and Cardoza 1982, Anderson 1987). There also may be another segment of the population that is nomadic. Nomadic individuals tend to be older and may establish temporary home ranges in areas containing key resources. Nomadic bobcats may not be excluded from the home ranges of residents as easily as transients and may require a more aggressive interaction with the resident to initiate movement (McCord and Cardoza 1982).

Chamberlain and Leopold (2001) found that male home range overlap with females was observed to be the greatest during the breeding season, whereas core areas were generally exclusive. Female home ranges and core area overlap were similar during all seasons (Chamberlain and Leopold 2001). Intrasexual overlap between female bobcats also may be affected by time-in-residence. Thus, females that become more familiar with the landscape and are more efficient hunters may tolerate greater overlap because of their ability to meet energetic demands while sharing portions of their home range. Females that produce kittens may tolerate an offspring's nearby residence following dispersal in areas where habitat quality is great, resulting in sharing of home range areas. Vacated home ranges also may allow offspring to disperse short distances, thereby enabling them to remain close to or overlap the home range of their mother (Griffith and Fendley 1986, Conner et al. 1999, Chamberlain and Leopold 2001). In areas where transient individuals are abundant, spatial organization may not change due to the quick occupancy of the vacated home ranges by transients (Litvaitis et al. 1987).

Study Area

The Joseph W. Jones Ecological Research Center (JWJERC) at Ichauway is located in southern Baker County, Georgia, 16 km south of Newton, Georgia. The research facility encompasses 11,735 ha and is bordered by almost 22 km of the Flint River on its southeastern side. Other hydrological components include Ichauwaynochaway Creek, which flows approximately 24 km through the study area and numerous depressional wetlands. Ichauway is located within the Dougherty Plain physiographic province in the southeastern Gulf Coastal Plain and consists primarily of flat to gently rolling karst topography. Elevations range from 27 to 61 m above sea level. Average temperatures range from 11.1^{o}C in winter to 27.2^{o}C in summer. Average annual rainfall totals 132 cm (JWJERC 1997, 2001).

Habitats at Ichauway include limesink wetlands, longleaf pine (*Pinus palustris*) woodlands, mixed hardwood areas, slash pine (*P. elliottii*) flatwoods, oak barrens, natural and oldfield loblolly pine (*P. taeda*) stands, food plots, agricultural fields, shrub-scrub upland, human/cultural, riparian hardwood hammocks, cypress-gum lime sink ponds, creek swamps, forested wetlands, and riverine areas (JWJERC 2001). Currently, the land area at Ichauway is composed of 60% multiple use zones that integrate wildlife and timber management. The remaining land area (40%) is maintained as conservation zones that are managed to conserve and restore the natural longleaf pine-wiregrass (*Aristida stricta*) landscape (JWJERC 2001).

Periodic prescribed fire is used at Ichauway to maintain the longleaf pine-wiregrass ecosystem, to reduce fuel build-up, as site preparation for pine regeneration, experimental research, and educational activities. Land managers at Ichauway burn approximately 4,000 to 4,900 ha annually, resulting in a 2-year burn rotation (Davis 2001, JWJERC 2001).

Ichauway was historically managed as a northern bobwhite (*Colinus virginianus*) hunting preserve. Consequently, various quail management practices are employed at the study site, primarily in the multiple use zones. Practices include: planting and maintaining food plots, supplemental feeding of bobwhite, and limited predator removal. Supplemental feeding and predator removal only occur in multiple use zones. Predators removed include racoons (*Procyon lotor*), Virginia opossum (*Didelphis virginiana*), striped skunks (*Mephitis mephitis*), coyotes (*Canis latrans*), and red foxes (*Vulpes vulpes*). Bobcats have not been removed since 1999. Food plots are not restricted to multiple use zones, although food plots within conservation zones are sparse and are maintained as white-tailed deer (*Odocoileus virginianus*) forage.

JUSTIFICATION

Historically bobcats (*Lynx rufus*) were harvested for the fur trade or predator removal associated with game management practices. The introduction of the Convention on International Trade of Endangered Species (CITES) regulated the export of bobcat furs, thereby increasing the need for management of bobcat populations. As a result, bobcat research efforts increased in the mid 1970's.

Conserving biodiversity across the landscape is currently at the forefront of wildlife management paradigms (Liu and Taylor 2002). The importance of apex predators in conserving biodiversity is critical to understanding the natural equilibrium that occurs within ecosystems (Estes 1996, Linnell and Strand 2000). The purpose of this study was to determine the response of resident bobcats to the removal of neighboring resident bobcats by quantifying changes in spatial organization and habitat use. We suggest that spatial organization and territoriality are linked closer to habitat quality than to population abundance and are dynamic processes that change as resource availability changes. Removing marked and unmarked adult bobcats and quantifying the response of marked neighboring bobcats in terms of home range size and habitat use before and after removal should provide insight into bobcat behavior and spatial organization. New data describing the spatial organization of bobcats could have major impacts on management decisions involving this and other solitary species. This effort is part of an ongoing study which began in December 2000.

OBJECTIVES

1. Determine the effects of reduced population abundance on bobcat home range size.
2. Determine the effects of reduced population abundance on bobcat habitat use.

THESIS FORMAT

I have written my thesis in manuscript format. Chapter 1 is an introduction and a literature review of prior bobcat research findings. Chapter 2 describes the experiment that I performed to determine the effects of removal on the spatial organization and habitat use of bobcats, which will be submitted to the Journal of Wildlife Management. Chapter 3 presents the summary and conclusions from my thesis research.

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CHAPTER 2

EFFECTS OF REMOVAL ON SPATIAL ORGANIZATION AND HABITAT USE OF BOBCATS[1]

[1]Lynch, G.S., L.M. Conner, R.J. Warren. 2005. To be submitted to Journal of Wildlife Management

Abstract: There are few experimental data available concerning spatial organization and habitat use of bobcats (*Lynx rufus*). Some observational studies have noted the relationship between established residents and neighboring conspecifics, however, these studies have not specifically addressed the effects of changing population abundance on spatial organization and habitat use of bobcats. We investigated bobcat spatial organization and habitat use relative to a decrease in population resulting from an experimental removal conducted on an 11,735-ha study site in southwestern Georgia. We divided our study area into a control area (about 3,521 ha), from which no bobcats were removed, and a treated area (about 7,041 ha), within which the bobcat population abundance was reduced by approximately 50%. In response to population reduction, male bobcats shifted ($F_{1,3}$=138.08, P= 0.0013) their home ranges more ($\bar{X}$ =26.5 + 1.7%) relative to baseline (ie., shift post-removal reported as a percentage of shift pre-removal), whereas males within the control area shifted their home ranges less ($\bar{X}$ =-28.07 + 5.54%) relative to baseline. Dispersion of radio locations differed as a function of removal for female bobcats that were exposed to the removal of a potentially interacting male ($F_{1,14}$=6.78, P=0.0209), or both a potentially interacting male and female ($F_{1,14}$=8.27, P=0.0122). When exposed to the removal of a male, dispersion (reported as a percentage of pre-removal dispersion) increased less for treatment females ($\bar{X}$ =7.9 + 7.3%) than for control females ($\bar{X}$ =41.24 + 11.1%). Likewise, when exposed to the removal of both a male and a female, dispersion increased less for treatment females ($\bar{X}$ =10.6 + 19.6%) than for control females ($\bar{X}$ =34.4 + 26.8%). Male bobcats may have shifted their home ranges to increase breeding opportunities. The difference in dispersion of control and treatment female radio locations may be the result of a decrease in intraspecific competition allowing for shorter, more-efficient feeding forays or possibly the result of less-detailed management or inspection of scent markings

along the boundary of the bobcat's territory. Neither habitat selection nor habitat use differed as a function of removal in this study, suggesting that density-dependent habitat selection was not occurring.

Key Words: bobcat, dispersion, habitat use, *Lynx rufus*, shift, spatial organization

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INTRODUCTION

Bobcat home ranges and spatial organization are thought to be controlled by numerous factors including prey abundance, habitat quality, breeding opportunities, den sites, and time-in-residence (Bailey 1974, Griffith and Fendley 1986, Clutton-Brock 1989, Conner et al. 1999). However, the factors that promote a solitary life are thought to be prey size and hunting mode. Smaller carnivores such as bobcats can easily kill prey smaller than themselves and have no need for cooperative hunting. In fact, the existence of conspecifics in a bobcat's immediate surroundings should theoretically have a negative effect on foraging efficiency by disturbing prey or depleting resources (Sandell 1989).

Bailey (1974) suggested that scarce prey or harsh weather may modify spatial organization with bobcats tolerating more or less overlap depending on the pressures of the local environment. He concluded that territoriality may occur only when prey is widespread and abundant. As bobcats adjust to changing environments, home range sizes may change fluidly when scarce resources are shared.

Benson et al. (2004) used a long-term telemetry data set to study reoccupation of home ranges following the death of a resident bobcat. They found 10 cases in which another bobcat assumed use of the vacated area after the death of a resident individual. Anderson (1988) removed a resident male bobcat and noted an overlapping resident male started using the vacated area within 6 days. Two other studies noted a range shift by neighboring females following the death of a resident (Bailey 1974, Litvaitis et al. 1987).

Presumably resource availability would need to be greater or more accessible in surrounding areas for it to be beneficial for a bobcat to shift or expand its home range (Lovallo and Anderson 1995). Whereas bobcat home ranges and core areas are generally exclusive, bobcats may investigate areas outside of their areas of use and be aware of adjacent resources, allowing them to adjust to changes in spatial organization within the population (Lovallo and Anderson 1995, Benson et al. 2004). If habitat is limiting and a better habitat is made available, it is expected that neighboring individuals would take advantage of the better habitat (Frettwell and Lucas 1970).

The first objective of this study was to quantify changes in dispersion of bobcat locations and shifts in central tendency before and after an experimental removal. The second objective was to quantify habitat selection and use at 2 spatial scales before and after an experimental removal for the same time periods. We hypothesized that the dispersion of animal locations would increase as space and resources became available, and that bobcats would select or use the best habitat available in response to a population reduction.

STUDY AREA

The Joseph W. Jones Ecological Research Center (JWJERC) at Ichauway is located in southern Baker County, Georgia, 16 km south of Newton, Georgia. The research facility encompasses 11,735 ha and is bordered by almost 22 km of the Flint River. Other hydrological components include Ichawaynochaway Creek, which flows approximately 24 km through the study area and numerous depressional wetlands. Average temperatures range from 11.1^{o}C in winter to 27.2^{o}C in summer. Average annual rainfall totals 132 cm (JWJERC 1997, 2001).

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Northern Bobwhite quail management practices are employed at the study site, primarily in the multiple use zones. Management practices include: planting and maintaining food plots, supplemental feeding of bobwhite, and limited predator removal. Supplemental feeding and predator removal only occur in multiple use zones. Predators removed include racoons (*Procyon lotor*), Virginia opossum (*Didelphis virginiana*), striped skunks (*Mephitis mephitis*), coyotes (*Canis latrans*), and red foxes (*Vulpes vulpes*). Bobcats have not been removed since 1999.

METHODS

Bobcat capture and handling

We captured bobcats with laminated, offset-jaw #1.75, and soft-catch #3 Victor coil spring traps (Victor Inc., Ltd., Cleveland, OH) that were modified with an additional box swivel and a double-stake swivel. Trap sets were baited with various attractants. Captured animals were restrained using a net and immobilized with an intramuscular injection of ketamine hydrochloride (10mg/kg of body weight; Seal and Kreeger 1987). Sex, body length, hind foot length, ear length, tail length, and weight were recorded for each captured animal. Length and weight were used to differentiate juveniles from adults (Crowe 1975). Animals determined to be adults were fitted with a 180-g VHF radio collar (Advanced Telemetry Systems, Isanti, MN). Additionally, each captured animal received a uniquely numbered tattoo in each ear and a DNA sample was taken from each ear using a 3mm punch. Bobcats were monitored for 8-24 hours and released at the capture site. Bobcat trapping began on the study area in December 2000 and continued periodically to maintain an adequate sample size. All trapping procedures were approved by the University of Georgia Institutional Care and Use Committee (IACUC #A990159).

Bobcat removal

The study area was divided into control (approximately 3,521 ha) and treated (approximately 7,041 ha) areas separated by a major highway (U.S. Highway 200). Removal trapping began on 1 January 2005 and the last bobcat was removed on 9 February 2005. Foot-hold traps were placed along roadsides throughout the treated area. Traps were set and then checked daily. Trapped animals were dispatched using a .22 caliber handgun. We also used a Johnny Stewart Wildlife Call (Hunters Specialties, Cedar Rapids, Iowa), a thermal-imaging camera (Raytheon Company, Waltham, Massachusetts), and a shotgun to attract and remove selected radio-collared individuals. Standard measurements and DNA were taken from all removed cats as described above.

Scent Stations

Scent station surveys have long been used in an attempt to quantify bobcat population abundance (Diefenbach et al. 1994). A scent station survey was developed for the study site utilizing 224 stations to quantify relative abundance of bobcats before and after removal, determine if visits before and after removal were independent of treated and control areas, and to ensure that rapid re-colonization and/or immigration did not occur. Stations were placed on alternating sides along roads at known points throughout the control and treated areas. A minimum buffer of 0.32 km (0.2 miles) was maintained between stations. An area of $1m^2$ was cleared and smoothed using a garden rake. A cotton ball saturated with bobcat urine was used as a lure and placed in the center of the cleared area. Scent stations were established and then checked for 3 consecutive mornings. The size of the study area called for a large number of scent stations; therefore, checks of stations were set up as Run A and Run B. Run B followed run A by 4 days and the same locations were used before and after bobcat removal. We obtained scent station data on the treated and control areas from 11 December 2004 – 17 December 2004 before bobcat removal, and then again from 16 February 2005 – 22 February 2004 following the removal.

Bobcat monitoring

Bobcats were triangulated using a 3-element yagi antenna, and a VHF-receiver (Wildlife Materials Inc., Carbondale, IL). A minimum of 2 azimuths were taken from known reference points throughout the study area. Time intervals between bearings were limited to less than 15 minutes to minimize error resulting from movement between readings (White and Garrott 1990). Eighty seven percent of the time intervals between bearings used for animal locations in this study were less than 6 minutes. A minimum of 30 locations per bobcat were recorded during each calendar season, and the locations were obtained equally throughout the diel period. A minimum of 8 hours was allowed between locations of individual bobcats to maintain independence among consecutive locations.

Data Analysis

Spatial data.—Compass bearings were converted to Universal Transverse Mercator (UTM) coordinates using the FORTRAN program EPOLY (L. M. Conner, pers. comm.). ArcGIS 9 (ESRI 2005) with the Hawth's Analysis Tools (www.spatialecology.com/htools) was used to create Minimum Convex Polygon (MCP) home ranges for individual bobcats for 4 months pre- and 4 months post-removal. We excluded 5% of the outermost radio locations to create 95% convex polygons.

Time periods for the study were baseline (30 April 2004 – 31 August 2004), pre-removal (1 September 2004 – 31 December 2004), removal (1 January 2005 – 14 February 2005), and post-removal (15 February 2005 – 15 June 2005). We calculated the bivariate medians (White and Garrott 1990) and dispersion (Van Valen 1978) for each bobcat's area of use before and after the removal using the FORTRAN program FIDELITY (L. M. Conner, pers. comm.). We used the bivariate median as our measure of central tendency to ensure that the measure of central tendency fell within actual points used in the study (Berry et al. 1984). Bivariate medians were calculated for each bobcat during baseline, pre-removal, and post-removal. A change in the bivariate median indicated a change in central tendency (e.g., a shifting home range). We compared the change in bivariate medians between the baseline and pre-removal time periods (i.e., the shift occurring between 2 pre-removal seasons) to the change in bivariate medians between the pre- and post-removal time periods (i.e., the shift occurring following the removal) for each bobcat. We standardized the shift in central tendency by subtracting shift time-2 from shift time-1 and dividing by dispersion time-1 so that it could be reported relative to dispersion.

We calculated dispersion (i.e., the mean distance between bivariate medians and animal locations; Van Valen 1978) for each bobcat for pre- and post-removal time periods. A change in dispersion indicated that the distribution of bobcat locations became either more or less dispersed as a function of removal. When comparing treatment and control bobcats, we standardized dispersal by reporting the change in dispersal (i.e., the difference between pre- and post-removal dispersal) as a proportion of pre-removal dispersal; thus removing variation associated with individual bobcat behavior.

The data were analyzed at 2 levels. We first compared the bobcats in the control area (N=5) to the bobcats in the treated area (N=16) using analysis of variance. We performed this analysis using all bobcats irrespective of sex; we then performed the analysis for each sex separately. We then placed a buffer zone that was 1.5 times larger than the radius of the average bobcat home range size in our study around each removal site using the buffer command in ArcGIS 9 (ESRI 2005). We used the intersect command in ArcGIS 9 (ESRI 2005) to determine which bobcats potentially interacted with adult bobcats that were removed. We repeated the above analysis using bobcats that potentially interacted with removed bobcats as “treated” and remaining bobcats as “control” animals. When analyzing data using potentially interacting animals, we did not analyze male-only data because all males (N=5) were considered to have interacted with removed bobcats; thus, there were no control animals.

Habitat data.—Digitized habitat types were organized into 8 categories: pine, mixed pine-hardwood, agriculture/food plot, hardwood, wetland, pine regeneration, and urban/barren. Habitat use and selection were tested for each scenario at Johnson's (1980) second (i.e., within the study area) and third orders (i.e., within the home range). We used a Euclidean distance technique to test for changes in habitat use and selection (Conner and Plowman 2001) in response to removal. Habitat selection was analyzed by comparing distances from animal locations to habitat types relative to the distances that would be expected at random, whereas habitat use was simply a comparison of habitat used before and after removal. We used a 2-factor multivariate analysis of variance (MANOVA) to quantify differences in habitat use and selection as a function of sex, treatment, and their interaction. The data were first analyzed using our original predetermined control and treated areas. We then used the buffer zones we created for the spatial analysis to determine animals that potentially interacted with removed bobcats to partition control and treated groups. Again, as with the spatial analysis, we did not look at the effects of removal on habitat use and selection of males that potentially interacted with removed bobcats because there were no males classified as control animals.

Scent station data.—We determined if there was a detectable difference in bobcat abundance within the treated and control areas using a chi-square test in a contingency table analysis (PROC FREQ; SAS Institute 2003) of our scent station data. A station was considered visited if a bobcat track was recorded within the cleared area. We first analyzed the data by counting each bobcat visit as a single bobcat being present (i.e., if a single station was visited on multiple runs during a sampling period, each visit was considered independent). We further analyzed the data by counting multiple bobcat visits to a station during a given run as a single visit. All statistical analyses were performed using SAS software (SAS Institute 2003).

RESULTS

Bobcat removal

Twenty five bobcats were radio-tracked from 30 April 2004 – 31 December 2004. On 1 January 2005 bobcat removal began; removal ended on 14 February 2005. Thirteen adult bobcats and 12 juveniles were removed. Four previously radio-collared bobcats were removed, leaving 21 remaining radio-collared bobcats for the post-removal time period (15 February 2005 – 15 June 2005).

Spatial data

In our first analysis using all study animals within the predetermined control and treated areas, we found that neither dispersion ($F_{1,19}$=0.31, P=0.5821) nor shift ($F_{1,19}$=0.08, P=0.7551) differed as a function of removal. Habitat selection at the second ($F_{8,39}$=0.66, P=0.7225) and third orders ($F_{8,39}$=0.94, P=0.4950) were unaffected by removal within the predetermined control and treated areas. Similarly, bobcat habitat use did not differ at the second ($F_{8,12}$=1.67, P=0.2041) or third orders ($F_{8,12}$=1.48, P=0.2599) as a function of removal within the predetermined control and treated areas. Dispersion also did not vary as a function of removal for females ($F_{1,14}$=0.67, P=0.4279) or males ($F_{1,3}$=0.51, P=0.5282). Shift did not differ as a function of removal for females ($F_{1,14}$=0.01, P=0.9151), but did differ for males ($F_{1,3}$=138.08, P=0.0013). Males in the treatment area had a larger shift ($\bar{X}$ =26.54 + 1.7%) relative to baseline (i.e., shift post-removal reported as a percentage of shift pre-removal), than males in the control area ($\bar{X}$ =-28.07 + 5.54%) (Figure 3.1).

Neither dispersion ($F_{1,14}$=0.43, P=0.5223) nor shift ($F_{1,14}$=0.57, P=0.4613) differed as a function of removal when comparing female bobcats that potentially interacted with removed females. Neither habitat selection at the second ($F_{8,21}$=0.44, P=0.8851) or third ($F_{8,21}$=1.03, *P*=0.4482) orders, nor habitat use at the second ($F_{8,8}$=0.86, *P*=0.5800) or third ($F_{8,13}$=1.45, *P*=0.2631) orders varied as a function of removal for female bobcats that potentially interacted with removed adult females.

Dispersion differed ($F_{1,14}$=6.78, *P*=0.0209) for females when a potentially interacting male was removed, with potentially interacting animals increasing less ($\bar{X}$ =7.8 + 7.31%) than control animals ($\bar{X}$ =41.24 + 11.09%) (Figure 3.2). Shift ($F_{1,14}$=0.03, *P*=0.8550) did not differ for females when a potentially interacting male was removed. Neither habitat selection at the second ($F_{8,21}$=0.21, *P*=0.9847) or third ($F_{8,21}$=0.61, *P*=0.7626) orders, nor habitat use at the second ($F_{8,8}$=1.11, *P*=0.4414) or third ($F_{8,13}$=0.59, *P*=0.7713) orders differed as a function of removal for female bobcats that potentially interacted with removed adult males.

Dispersion differed ($F_{1,14}$=8.27, *P*=0.0122) for females when both a potentially interacting male and female were removed, but shift did not ($F_{1,14}$=0.00, *P*=0.9733). Dispersion (reported as a percentage of pre-removal dispersion) of potentially interacting animals increased less ($\bar{X}$ =10.6 + 19.6%) than control animals ($\bar{X}$ =34.4 + 26.8%) (Figure 3.3). Neither habitat selection at the second ($F_{8,21}$=0.53, *P*=0.8225) or third ($F_{8,21}$=0.62, *P*=0.7481) orders, nor habitat use at the second ($F_{8,8}$=1.09, *P*=0.4549) or third ($F_{8,13}$=0.70, *P*=0.6877) orders differed as a function of removal for female bobcats when both a potentially interacting male and female were removed.

Scent station data

When each bobcat visit was an individual observation, bobcats were recorded present at 9 stations in the control area before removal and at 11 stations after removal. In contrast, 50 stations were visited before the removal in the treated area, and only 21 were detected following the removal, resulting in a relative reduction of about 58% (Figure 3.4). Bobcat visits were dependent (P=0.0354) on treatment and time, providing evidence that rapid immigration did not occur following removal.

We further analyzed the data by counting multiple visits by a bobcat to a given station during a given run (before or after) as a single visit. Bobcats were recorded present at 9 stations in the control area before removal and at 11 stations after the removal. In contrast, 42 stations were visited before the removal in the treated area, and only 20 were detected following the removal, representing an approximate reduction of 52% (Figure 3.5). Bobcat visits were dependent (P=0.0682) on treatment and time. Thus, regardless of analysis approach, our removal resulted in a substantial reduction (about 50%) in population abundance, and removed bobcats were not replaced by rapidly colonizing individuals.

DISCUSSION

Previous studies have noted that a land tenure system may exist for bobcats and that available territory may not become available for use by neighboring or transient individuals prior to the death of the resident. These researchers documented the replacement of a previously occupied home range by a transient or non-resident bobcat (Bailey 1974, Lovallo and Anderson 1995, Anderson 1988, Benson et al. 2004). Other researchers also report that habitat quality (i.e., greater prey abundance) may be the limiting factor determining spatial arrangement and habitat use (Anderson 1987, Rucker et al. 1989). Bailey (1974) also suggested that in areas where prey abundance is variable, territoriality may break down as bobcats move to needed resources, and that territoriality may occur only when prey populations are abundant and distributed evenly. We suggest that in areas where prey species are abundant, transient individuals may not meet as much resistance when trying to settle within an area. Further energetic demands associated with defending a large area may not be useful to bobcats if needed resources can be obtained in a smaller area.

In our study, when female bobcats were exposed to removal of a neighboring male or both a male and female resident, their location dispersion, or home range size, increased less than those that did not potentially interact with a removed resident. Female home range size is thought to be closely related to prey abundance. Therefore, reducing bobcat abundance may have a similar effect on spatial organization as an increase in prey availability. Thus, the absence of conspecifics in neighboring areas may increase foraging efficiency (Sandell 1989). If this is so, then the competition for resources in areas of overlapping home ranges may be reduced and may allow bobcats to obtain needed resources during shorter feeding forays, resulting in decreased dispersion. We saw no significant shifts in female home ranges. This coupled with no significant changes in habitat selection or use supports the idea that habitat quality dictates the establishment of female bobcat home ranges.

The spatial arrangement of bobcats may not be stable from year to year or between seasons. Fendley and Buie (1986) reported that home range sizes increased substantially from previous studies in the 1960's, presumably as a result of an increase in planted pine plantations and a corresponding decrease in early successional habitats leading to decreased small mammal populations. During times when prey is scarce or harsh environmental conditions impede normal movements, bobcat spatial organization may be modified to adapt to the changing environment (Bailey 1974).

Our study area has abundant small mammal populations as a result of routine prescribed fire and intensive northern bobwhite management practices (Godbois et al. 2004). We suggest that in areas of excellent habitat with abundant and evenly distributed prey, or in areas of poor habitat with sparse and patchily distributed prey, spatial organization and territoriality may breakdown in its basic sense (Knick 1990). It seems likely that in either of these situations it would be energetically inefficient to intensively defend an area. In fact, territoriality may only be beneficial when habitat quality and prey abundance are average, providing the minimum amount of resources required by bobcats. When prey availability becomes localized or very mobile, bobcats may move from their normal areas of use; thus, exclusive areas would not be of much use (Bailey 1974). Lovallo and Anderson (1995) suggested that female bobcats may be aware of available resources located within the home ranges of neighboring individuals. Relying on the idea that habitat selection and use is density dependent we expected bobcats to select better habitats after removal (Fretwell Lucas 1970). The results of our analysis suggest that habitat is not limiting within the study area. In areas with excellent habitat and abundant prey it is unlikely that a bobcat would shift or expand its home range into a vacated area if its current home range is of better or equal quality with regard to habitat quality and prey abundance. Assuming that time-in-residence increases the efficiency at which a bobcat moves to and from resources within its area of use (Conner et al. 1999), it would then seem likely that the bobcat would remain in its home range. Likewise, extended periods in a home range should increase the resident bobcat's familiarity with the surrounding landscape, thereby allowing it to move to areas of better resources when they become available (Lovallo and Anderson 1995).

Male bobcat spatial distribution is thought to be dependent on availability of females, at least during the breeding season (Sandell 1989). We found that when neighboring bobcats were removed, which resulted in a decreased population, male bobcats shifted their home ranges. Males likely shifted their home ranges to seek out females for breeding opportunities. We suggest that the decrease in female dispersion or the reduction in the number of breeding-age females, or a combination of both may be responsible for the shift in central tendency exhibited by male bobcats.

Identifying limiting resources in each system is critical to understanding the fluctuation of spatial organization in a bobcat population. Further research on habitat and its contributions to the spatial arrangement of bobcats will extend the understanding of bobcat ecology and improve management of the species.

MANAGEMENT IMPLICATIONS

Removing adults may allow juvenile or transient individuals to assume residency of a vacated area of use. The change in territorial behavior in response to a population reduction may be an important means of increasing genetic diversity through immigration as available habitat becomes sparse. Bobcat removal or predator removal in general, is a management tool employed on the majority of quail plantations located near the study area in southwest Georgia. When bobcats are removed during a predator management program, it is likely that another juvenile or transient bobcat will move into the vacated area of use soon after removal thereby requiring very frequent trapping throughout the year to ensure extirpation.

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Figure 3.1. Changes in home range shift for male bobcats using predetermined control and treatment areas following removal of approximately 50% of the bobcats from the treatment area, Ichauway, Georgia, 2005.

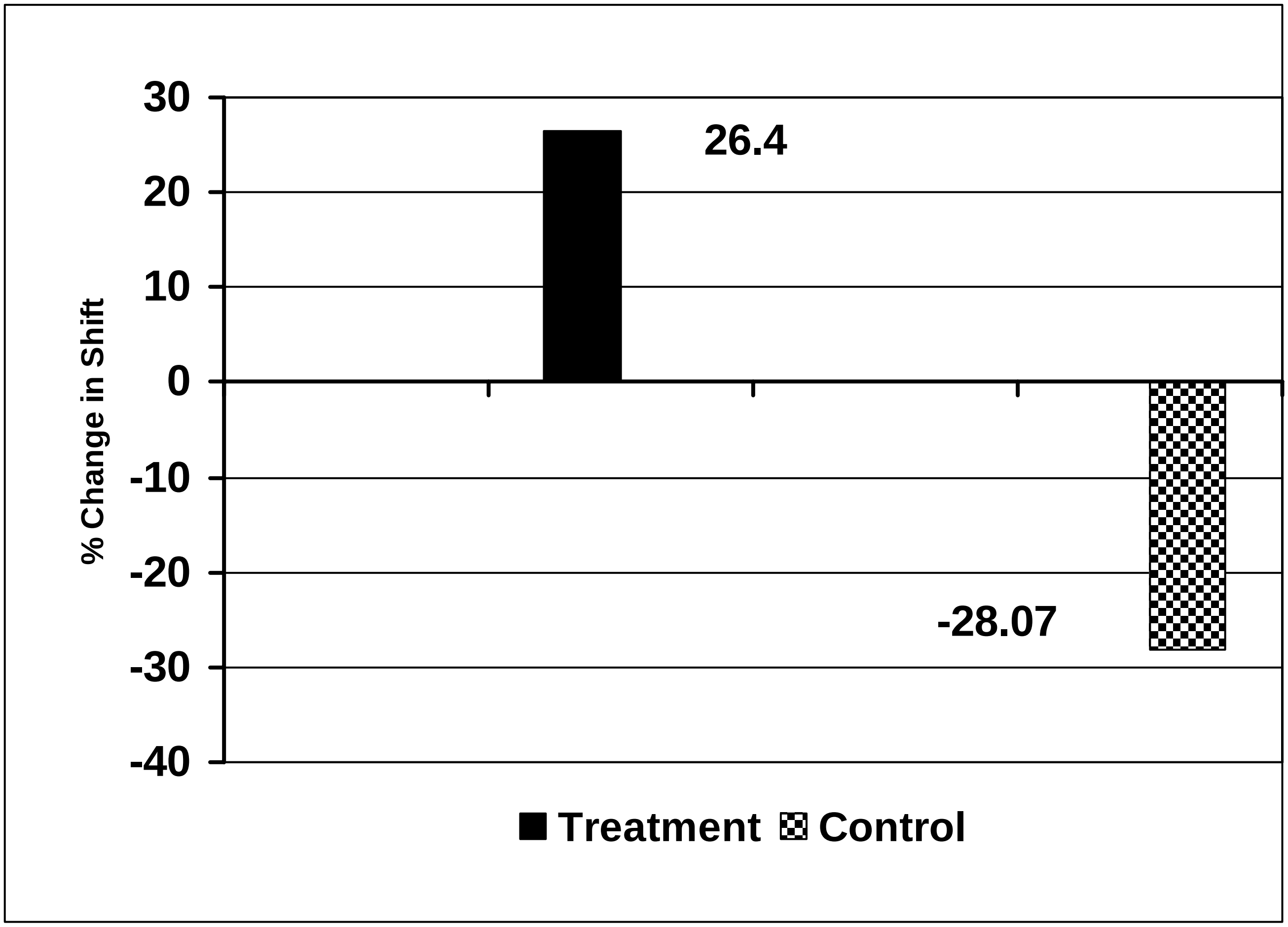

30
20
10
0
-10
-20
-30
-40
% Change in Shift
26.4
-28.07
Treatment
Control

Figure 3.2. Changes in home range dispersion for females that potentially interacted with removed males following removal of approximately 50% of the bobcats from the treatment area, Ichauway, Georgia, 2005.

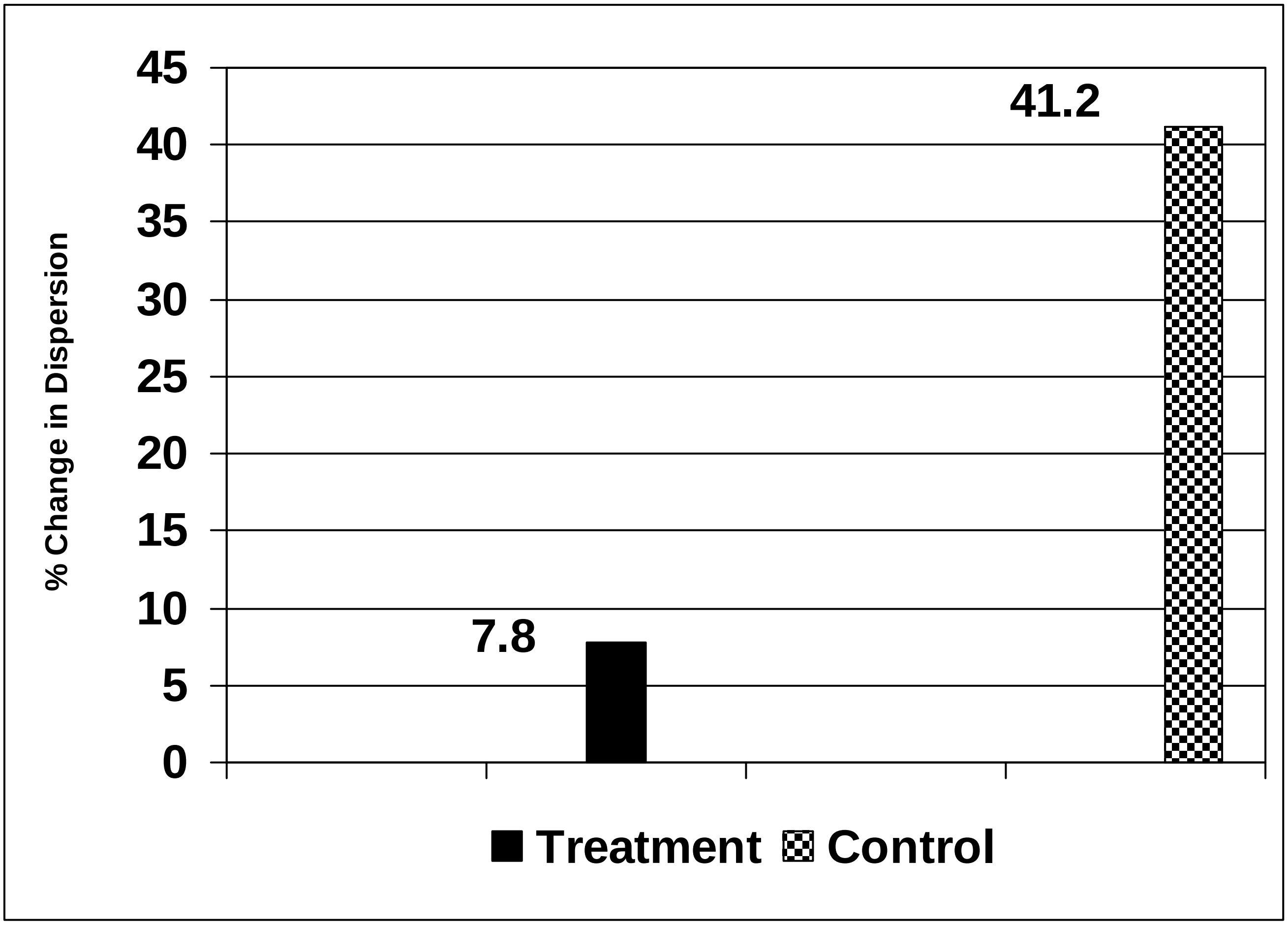

% Change in Dispersion
45
40
35
30
25
20
15
10
5
0
41.2
7.8
Treatment
Control

Figure 3.3. Changes in home range dispersion for females that potentially interacted with both a removed male and female following removal of approximately 50% of the bobcats from the treatment area, Ichauway, Georgia, 2005.

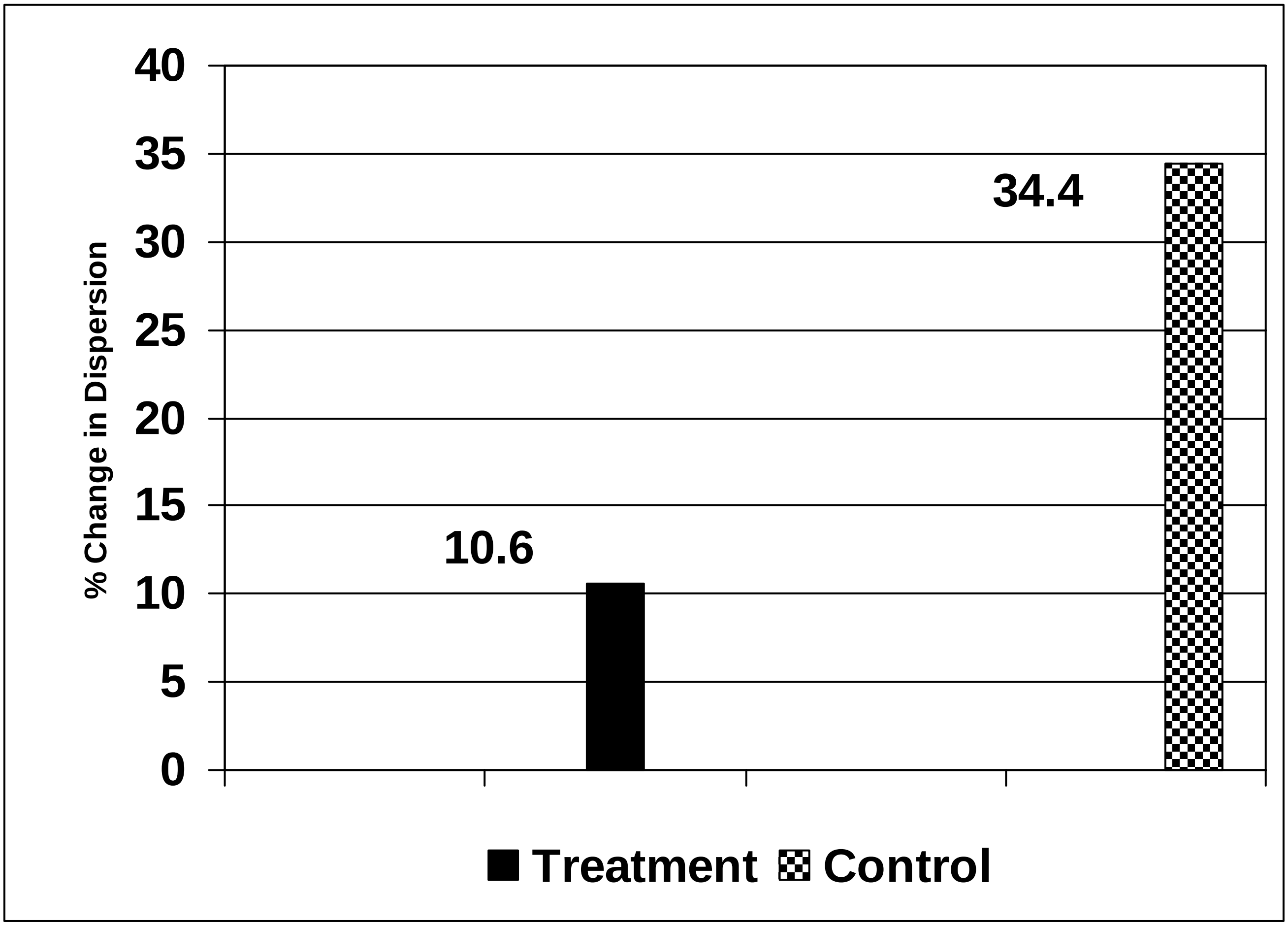

40
35
30
25
20
15
10
5
0
% Change in Dispersion
34.4
10.6
Treatment
Control

Figure 3.4. Bobcat scent station visits (counting multiple visits as independent) for control and treatment areas, both before and after removal of approximately 50% of the bobcats on the treatment area, Ichauway, Georgia, 2005.

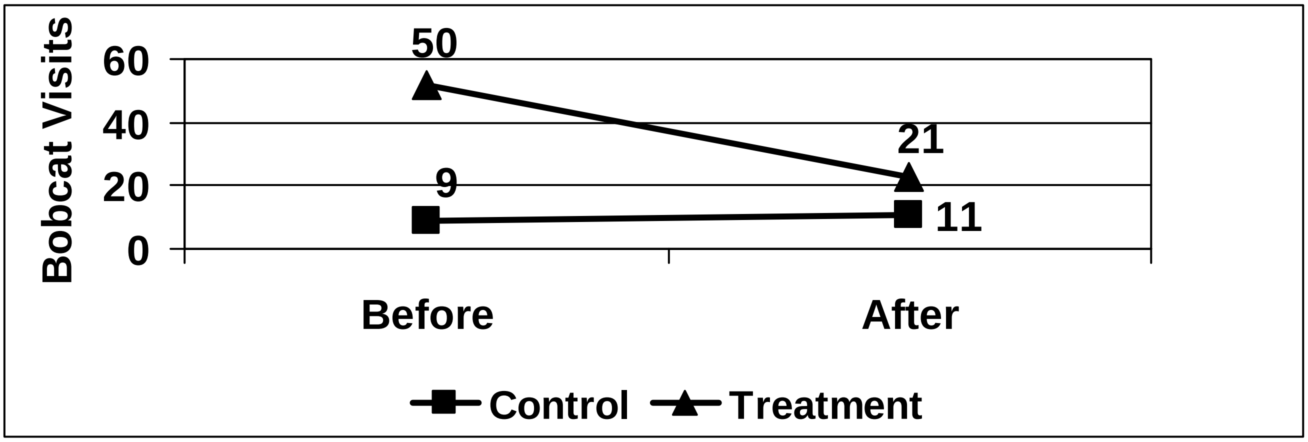
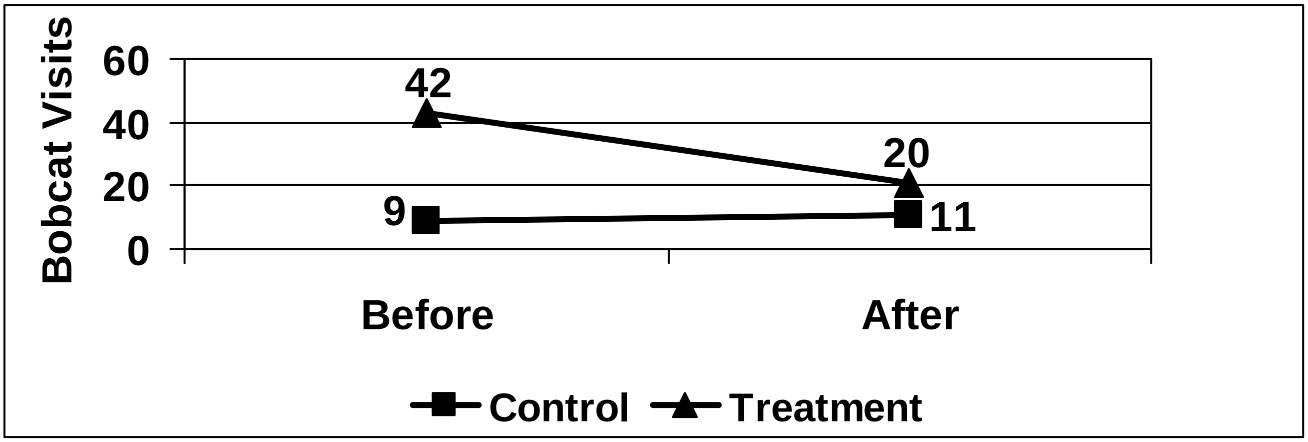

Bobcat Visits
60
40
20
0
50
21
9
11
Before
After
Control
Treatment

Figure 3.5. Bobcat scent station visits (counting multiple visits as a single visit) for control and treatment areas, both before and after removal of approximately 50% of the bobcats on the treatment area, Ichauway, Georgia, 2005.


Bobcat Visits
60
40
20
0
42
20
9
11
Before
After
Control
Treatment

CHAPTER 3

SUMMARY AND CONCLUSIONS

There are few experimental data available concerning spatial organization and habitat use of bobcats (*Lynx rufus*). Some observational studies have attempted to examine the relationship between established residents and neighboring conspecifics, however, these studies have not specifically addressed the effects of changing population abundance on spatial organization and habitat use of bobcats. Our objective was to quantify the effect of reduced population abundance on spatial organization and habitat use of bobcats (*Lynx rufus*).

We investigated bobcat spatial organization and habitat use relative to a decrease in population resulting from an experimental removal conducted on an 11,735-ha study site in southwestern Georgia. We divided our study area into a control area (about 3,521 ha), from which no bobcats were removed, and a treated area (about 7,041 ha), within which the bobcat population abundance was reduced by about 50%. Dispersion of animal locations and shifts in central tendency were used to quantify changes in spatial arrangement. Habitat use was analyzed at 2 spatial scales, Johnson's 2^{nd} and 3^{rd} orders (Johnson 1980).

Previous studies have noted that a land tenure system may exist for bobcats and that available territory may not become available for use by neighboring or transient individuals prior to the death of the resident. These researchers documented the replacement of a previously occupied home range by a transient or non-resident bobcat (Bailey 1974, Lovallo and Anderson 1995, Anderson 1988, Benson et al. 2004). Other researchers also report that habitat quality (i.e., greater prey abundance) may be the limiting factor determining spatial arrangement and habitat use (Anderson 1987, Rucker et al. 1989). We suggest that in areas where prey species are abundant, transient individuals may not meet as much resistance when trying to settle within an area. Further energetic demands associated with defending a large area may not be useful to bobcats if needed resources can be obtained in a smaller area.

In our study, when female bobcats were exposed to removal of a neighboring resident of either sex, their location dispersion, or home range size, decreased. Female home range size is thought to be closely related to prey abundance. Therefore, reducing bobcat abundance may have a similar effect on spatial organization as an increase in prey availability. Thus, the absence of conspecifics in neighboring areas may increase foraging efficiency (Sandell 1989). If so, then the competition for resources in areas of overlapping home ranges may be reduced and may allow bobcats to obtain needed resources during shorter feeding forays, resulting in decreased dispersion. Thus, the spatial arrangement of bobcats may not be stable from year to year or between seasons. Most findings suggest that spatial organization is a dynamic process that changes as resource availability changes (Bailey 1974, Fendley and Buie 1986).

Our study area has abundant prey as a result of routine prescribed fire and intensive northern bobwhite management practices (Godbois et al. 2004). We suggest that in areas of excellent habitat with abundant and evenly distributed prey, or in areas of poor habitat with sparse and patchily distributed prey, spatial organization and territoriality may breakdown (Knick 1990). It seems likely that in either of these situations it would be energetically inefficient to intensively defend an area. In fact, territoriality may only be beneficial when habitat quality and prey abundance are average, providing the minimum amount of resources required by bobcats. When prey availability becomes localized or very mobile, bobcats may move from their normal areas of use; thus, exclusive areas would not be of much use (Bailey 1974).

Bobcats may be aware of resources within the home ranges of neighboring individuals (Lovallo and Anderson 1995). In areas with excellent habitat and abundant prey it is unlikely that a bobcat would shift or expand its home range into a vacated area, if its current home range is of better or equal quality with regard to habitat quality and prey abundance. Assuming that time-in-residence increases the efficiency at which a bobcat moves to and from resources within its area of use (Conner et al. 1999), it would then seem likely that the bobcat would remain in its home range unless habitat quality of an adjacent area surpassed some threshold. Likewise, extended periods in a home range should increase the resident bobcat's familiarity with the surrounding landscape, thereby allowing it to move to areas of better resources when they become available (Lovallo and Anderson 1995).

Male bobcat spatial distribution is thought to be dependent on availability of females, at least during the breeding season (Sandell 1989). Males likely shifted their home ranges to seek out females for breeding opportunities. We found that when neighboring bobcats were removed, resulting in a decreased population, male bobcats shifted their home ranges. We suggest that the decrease in female dispersion, or the reduction in the number of breeding-age females, or a combination of both may be responsible for the shift in central tendency exhibited by male bobcats.

Removing adults may only allow juvenile or transient individuals to assume residency of a vacated area of use. The change in territorial behavior in response to removal of bobcats may be an important means of increasing genetic diversity through immigration as available habitat becomes sparse. Furthermore, when bobcats are removed during a predator management program, it is likely that another juvenile or transient bobcat will move into the vacated area of use soon after removal.

Identifying limiting resources in each system is critical to understanding the fluctuation of spatial organization in a bobcat population. Further research on habitat use and its contributions to the spatial arrangement of bobcats will extend the understanding of bobcat ecology and improve management of the species.

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