

Annual Dynamics of Bobcat (*Lynx rufus*) Home Range and Core Use Areas in Mississippi

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ABSTRACT.—We investigated the annual dynamics of bobcat (*Lynx rufus*) home range and core use areas by radiotracking 23 female and 6 male bobcats from 10 January 1989 to 31 January 1998 in Mississippi. We quantified space use by measuring changes in the dispersion and central tendency of bobcat locations (*i.e.*, radiotelemetry locations) between annual home range and core use areas. Data from 38 female and 11 male home range and core area comparisons were used to examine bobcat spatial dynamics. Mean dispersion of home range and core use areas was greater for male than female bobcats, but dispersion for these areas did not differ between years for male or female bobcats. Annual shifts in the central tendency of home range and core use areas for female bobcats likely were a space-use strategy to optimize access to prey resources. Annual shifting of core area central tendency within non-shifting home ranges of male bobcats appeared to be a response to female spatial re-adjustments. Shift distance, after standardizing as a proportion of dispersion, did not differ between male and female bobcat home range and core use areas. Bobcat space use may be more dynamic than previously reported, particularly at the core-area spatial scale.

INTRODUCTION

Burt (1943) defined an animal's home range as the area used by an individual during its normal activities, such as food gathering, resting, mating and caring for young. The area within the boundary of an individual's home range is generally used disproportionately (Burt, 1943; Adams and Davis, 1967; Ewer, 1968; Leuthold, 1977) and selected areas of concentrated use are denoted as core areas (Burt, 1943; Kaufman, 1962; Ewer, 1968). The core area concept implies that sites of concentrated use contain the most dependable resources (Leuthold, 1977) and are of greater significance to the animal than less frequently used sites within the home range. While exploiting resources, solitary carnivores such as the bobcat (*Lynx rufus*) use areas (*i.e.*, core areas) within their home range that contain the most abundant resources (Bailey, 1981; McCord and Cardoza, 1982; Sandell, 1989; Conner, 1991). If resources become depleted or biological needs change, bobcats may shift or expand movement patterns to include areas containing a greater abundance of resources (Bailey, 1974; Buie *et al.*, 1979; Anderson, 1987; Knick, 1990; Lovallo and Anderson, 1995). Several studies have examined the size and boundary overlap of bobcat core-use areas

(Conner, 1991; Plowman, 1997; Chamberlain and Leopold, 2001; Nielsen and Woolf, 2001), but little is known about the annual dynamics of bobcat core-use areas within the home range.

An animal's home range commonly is identified by collecting a series of independent radiotelemetry locations for an individual over a specified period of time (Cochran, 1980). Continual reoccurrence of an animal to the same home range between identified time intervals indicates spatial fidelity (White and Garrott, 1990), whereas a shift or expansion of the home range between periods of interest suggests a lack of spatial fidelity. Past bobcat studies reported extensive overlap between annual home range boundaries for individual bobcats (Hamilton, 1982; Liviatis *et al.*, 1987; Rucker *et al.*, 1989; Nielsen and Woolf, 2001), suggesting that bobcats exhibited strong range fidelity (Phillips *et al.*, 1998; Van Dyke *et al.*, 1998). However, temporal changes in bobcat locations (*i.e.*, radiotelemetry locations) between annual home ranges may occur while having little effect on the spatial overlap of corresponding home range boundaries. Statistically testing for changes in dispersion and central tendency of bobcat locations between periods of interest provides a finer scale analysis to quantify home range fidelity. Further, assessing fidelity for home range and core use areas allows for investigations of bobcat space use at multiple spatial scales. The goal of this study was to investigate annual home range and core area fidelity for bobcats. Our objective was to investigate the dynamics of bobcat space use by testing for changes in dispersion and central tendency of bobcat locations between annual home range and core use areas.

METHODS

Study area.—Research was conducted on the 14,410 ha Tallahala Wildlife Management Area (TWMA) located in the Strong River District of the Bienville National Forest, approximately 16 km southeast of Newton, Mississippi. The landscape was flat to gently rolling. Climate was characterized by mild winters and long humid summers with a mean annual temperature of 18 C and 152 cm annual precipitation (Carraway, 1990).

The TWMA contained 29% mature (>50 y old) pine (*Pinus* sp.) with loblolly pine (*P. taeda*) as the dominant species. Pine plantations between 1–15 y old comprised about 15% of TWMA and averaged 19 ha in size. Mixed pine-hardwood and mature bottomland hardwood dominated by oak (*Quercus* sp.) and hickory (*Carya* sp.) accounted for 17% and 33% of the study area, respectively. Clear-cutting followed by pine regeneration through mechanical site preparation and planting or by the seed tree method were common silvicultural practices on TWMA. In November 1992 a tornado transected TWMA converting about 5% (770 ha) of the study area to early successional habitats. Most of the damage area was replanted to loblolly pine while 3 blocks of 40 ha each were burned annually to retain prairie-like communities.

Capture and monitoring of bobcats.—We captured bobcats with numbers 1.5 and 3 Victor soft-catch traps (Woodstream, Lititz, Pennsylvania). Trapping occurred annually from 10 January to 15 March 1989 to 1997. We trapped throughout the study area each year in attempt to capture unmarked adult individuals and to replace radiotransmitters on previously marked individuals. The number of traps operated nightly varied according to weather conditions but typically ranged between 35 and 70. Following capture, we chemically immobilized bobcats with ketamine hydrochloride (Ketaset Veterinary Products, Fort Dodge Laboratories Inc, Fort Dodge, Iowa) at 15 mg/kg of body mass. Bobcats were weighed and aged based on tooth eruption, teat condition of females and scrotum size of males (Crowe, 1975). Adult bobcats were fitted with a 125–225 g radio-transmitter (Advanced Telemetry Systems, Isanti, Minnesota and Wildlife Materials Inc., Carbondale, Illinois), monitored during recovery and

released at their original capture site. Animal capture and handling procedures were conducted under the auspices of Mississippi State University Institutional Animal Care and Use Committee protocol 93-032.

We used TRX-2000S radiotelemetry receivers and hand-held 3-element Yagi antennas (Wildlife Materials Inc, Carbondale, Illinois) to locate bobcats ≥ 2 times/wk over a 9-y period. Bobcat locations were triangulated from established telemetry stations distributed throughout the study area (White and Garrott, 1990). Telemetry tracking was conducted over the 24-h diel period and locations for each individual were separated by >12 h to maintain independence between consecutive locations. Azimuths were recorded within 15 min time intervals (\bar{x} = approx 4 min) to reduce error associated with bobcat movement and triangulation angles were maintained between 45° and 135° to reduce polygon error (Kitchings and Story, 1979). Bearing accuracy was $\pm 5.9^\circ$ across the study period. Therefore, a circle circumscribing each bobcat location 1 km from each telemetry station would have an approximate area of 3.4 ha. We derived Universal Transverse Mercator coordinates (*i.e.*, bobcat locations) from azimuths using program TELEBASE (Wynn *et al.*, 1990).

Data screening.—We standardized bobcat locations for equal monitoring duration and sampling intensity. Initially, locations were stratified into annual time intervals (*i.e.*, 1989, 1990, 1991, etc.) for each bobcat. For home range and core area fidelity comparisons, consecutive time intervals were paired for each animal to create data groups (*i.e.*, 1989–1990, 1990–1991, etc.). Thus, an individual had to be monitored during a minimum of two consecutive time intervals to be included in the analysis. Because of within year differences of mortality, transmitter failure and time of capture, monitoring duration between consecutive time intervals often differed. As a result, the length of time intervals for each data group was standardized to include equal monitoring duration. For example, if a bobcat was monitored 11 consecutive months during the first year and 12 consecutive months the second year, only the corresponding 11 mo of the second year were used for the group comparison. Similarly, the number of locations for an individual often differed between consecutive time intervals. To ensure equal sampling intensity, locations from the year with the greatest number of locations were randomly deleted until both years of the data group contained an equal number of bobcat locations.

Analysis.—We estimated home range (95%) and core area (50%) contour intervals using an adaptive kernel estimator in program CALHOME (Kie *et al.*, 1994). The fewest number of locations used in our analysis was 38, exceeding the recommended minimum suggested by Seaman *et al.* (1999). Annual home range and core area contour intervals and bobcat locations were converted to ARC/INFO polygon and point coverages (*i.e.*, a thematic map; ESRI, 1992). Respective point and polygon coverages were overlaid and all points exterior to their polygons were deleted. Resulting point coverages or distributions were used to test null hypotheses that bobcat locations for home range and core use areas did not differ in dispersion or central tendency between years for data groups.

To examine changes in dispersion, we calculated the bivariate median (Berry *et al.*, 1984) for the distribution of each bobcat's annual home range. We used the average distance between bobcat locations and the bivariate median center as our estimate of dispersion. Dispersion estimates for years 1 and 2 of each data group (*i.e.*, for consecutive home range areas for each bobcat) were compared using a paired *t*-test to determine if dispersion of bobcat home range distributions differed between years of monitoring. Differences in home range dispersion between male and female bobcats was compared using a 2-sample *t*-test. Annual differences in core area dispersion were estimated in the same manner.

To examine changes in central tendency, we calculated the bivariate median (Berry *et al.*, 1984) for the distribution of each bobcat's annual home range and core use area. The

distance (m) between bivariate median centers for years 1 and 2 of each bobcat's data group was calculated to measure the change in central tendency, hereafter referred to as a shift distance, between consecutive home range or core area distributions. We used bivariate medians to examine changes in central tendency because this measure always falls within the center of bobcat locations, whereas bivariate means may fall within areas devoid of bobcat locations (Berry *et al.*, 1984). To statistically quantify shift distances, we calculated a threshold value for each bobcat by multiplying the estimate of dispersion for year 1 of the home range and core area, as required, by 0.5. Threshold values then were compared to respective shift distances using a paired *t*-test to determine if bobcats shifted the central tendency of their home range and core use areas between years of monitoring. Thus, we defined a significant shift in central tendency as having a shift distance $>$ the threshold value (*i.e.*, dispersion for year one multiplied by 0.5). A significant *t*-statistic suggests that ≥ 0.5 of an individual's home range or core area distribution shifted to a new area during the second year of monitoring. In addition to gender-specific tests, a 2-sample *t*-test was used to compare home range and core area shift distances between sexes. Data were standardized by dividing the shift distance by dispersion of home range or core areas for year one to allow for statistical comparisons. Thus, data associated with the comparison of shift distance between sexes represents the shift as a proportion of year one dispersion.

RESULTS

We monitored 23 female and 6 male adult bobcats from 10 January 1989 to 31 January 1998. Data from 38 female and 11 male annual home range and core area comparisons were used to examine spatial dynamics.

Dynamics of female bobcat space use.—Mean (\pm SE meters) dispersion decreased ($t_{37} = 1.84$, $P = 0.07$) by 83.42 ± 45.31 for female home ranges and by 91.72 ± 53.96 for female core areas ($t_{37} = 1.70$, $P = 0.10$) between years 1 and 2 of the data groups. Central tendency shifted ($t_{37} = 3.29$, $P = 0.002$) between years by 323.28 ± 98.17 for female home ranges and by 826.11 ± 127.97 for female core areas ($t_{37} = 6.46$, $P < 0.001$).

Dynamics of male bobcat space use.—Mean dispersion was similar ($t_{10} = 0.24$, $P = 0.82$) between years 1 and 2 of the data groups for male home ranges (29.50 ± 123.75) and core areas (108.56 ± 132.38 ; $t_{10} = 0.82$, $P = 0.43$). Central tendency remained consistent ($t_{10} = 1.33$, $P = 0.21$) between years for male home ranges (540.86 ± 405.17) but shifted ($t_{10} = 2.89$, $P = 0.02$) for male core areas (994.47 ± 344.48).

Dynamics of male and female bobcat space use.—Mean dispersion of home ranges was greater ($t_{10,37} = 5.16$, $P < 0.001$) for male (1437.74 ± 332.05) than female (986.33 ± 37.42) bobcats and mean dispersion of core areas was greater ($t_{10,37} = 3.94$, $P < 0.001$) for male (972.71 ± 100.92) than female (341.53 ± 36.70) bobcats. Shift distances, after standardizing as a proportion of year one dispersion, for home range areas did not differ ($t_{10,37} = 0.83$, $P = 0.41$) between male (0.31 ± 0.11) and female (0.25 ± 0.03) bobcats. Similarly shift distances for core areas did not differ ($t_{10,37} = 0.54$, $P = 0.59$) between male (0.49 ± 0.13) and female (0.57 ± 0.07) bobcats.

DISCUSSION

Fundamental factors influencing bobcat space use are prey abundance and dispersion (Bailey, 1981; Anderson, 1987). Several studies reported that bobcats compensate for low prey availability by expanding home range size (Buie *et al.*, 1979; Knick, 1990). Bobcats on TWMA maintained relatively consistent patterns of home range and core area dispersion among years, indicating that bobcats were able to secure sufficient prey resources without expanding home range and core area size over time. However, space use by bobcats on

TWMA was more closely associated to shifting central tendency rather than expanding dispersion of home range and core use areas, particularly for females.

Previous bobcat studies reported a high percentage of overlap between annual home range boundaries for individual bobcats (Hamilton, 1982; Liviatis *et al.*, 1987; Rucker *et al.*, 1989; Nielsen and Woolf, 2001), suggesting that bobcats did not shift their home range areas among years. We concluded that female bobcats annually shifted the central tendency of their home range distributions, resulting in >0.5 of an animals home range distribution being shifted to a new location during the second year of monitoring. Home range shifts may be related to the acquisition of resources for meeting energetic requirements or, alternatively, a luxury afforded by abundant resources (Bailey, 1974) and low consensual competition. Lovallo and Anderson (1995) observed a female bobcat shift her home range area to encompass localities of better habitat quality and prey abundance when a neighboring female died and similar observations were reported by Benson *et al.* (2004). During our study, shifts between annual home ranges were universal among neighboring female bobcats, indicating that home range shifts were not solely related to the mortality of a neighboring female.

Female bobcats also shifted core use areas during the second year of monitoring which is similar with findings from other bobcat studies (Nielsen and Woolf, 2001). Female bobcat survival and reproduction is dependent upon securing adequate food and cover. If resources are concentrated within an ecosystem, bobcat space use should reflect resource distribution (Buie *et al.*, 1979; Bailey, 1981; Knick, 1990); resulting in fidelity for areas (*e.g.*, core areas) containing localized resources. Timber harvest practices on TWMA created an abundance of bobcat habitat structure for resting and denning opportunities (Conner, 1991; Plowman, 1997; Chamberlain, 1999; Chamberlain *et al.*, 2003) and observed shifts in cores areas indicate that female bobcats were able to secure adequate resting and denning cover without continually returning to the same core area.

Female bobcats may adjust space use in response to changing prey availability (Buie *et al.*, 1979, Anderson, 1987, Knick, 1990). Because animals spend most of their time within core areas (Burt, 1943; Kaufman, 1962; Ewer, 1968; Nielsen and Woolf, 2001), most hunting activities should occur within the core area. If hunting activities result in suppressing prey resources (Anderson, 1987), bobcats may adjust space use to include areas that contain a greater abundance of prey (Bailey, 1981; McCord and Cardoza, 1982; Sandell, 1989; Conner, 1991). Similarly, space use adjustments by female bobcats on TWMA indicate that shifts between annual core areas were closely tied to hunting activities and used as a means to optimize access to needed prey resources. In addition, if core areas contain the most dependable resources (Leuthold, 1977) and are used more intensively than other parts of the home range (Burt, 1943; Adams and Davis, 1967; Ewer, 1968; Leuthold, 1977), then shifting core areas could influence the spatial dynamics of an individual's home range (Conner *et al.*, 1999), as was observed for female bobcats on TWMA.

Consensual density also may influence bobcat space use (Zezulak and Schwab, 1979; Rolley, 1985; Sandell, 1989; Phillips *et al.*, 1998). Phillips *et al.* (1998) indicated that energetic stress associated with elevated density levels caused female martens (*Martes americana*) to completely abandon their home ranges. Social pressures associated with increasing densities of female bobcats on TWMA (Conner *et al.*, 1999; Benson *et al.*, 2004) did not prevent females from annually shifting home range and core use areas. At current density levels, we hypothesize that shifts in space use by female bobcats on TWMA were more likely a function of resource acquisition than the presence of neighboring consensuals. Shifting space use generally is a gradual process, not a single dramatic event. Temporally monitoring and adjusting scent marking intensity (Provost *et al.*, 1973; Bailey, 1974;

Guenther, 1980; McCord and Cardoza, 1982) within areas of preferred resource abundance could allow female bobcats to gradually shift core and home range areas with little violation of a neighboring individual's core area (Chamberlain and Leopold, 2001; Nielsen and Woolf, 2001). Such movement patterns provide female bobcats the opportunity to access areas of productive resources while minimizing antagonistic encounters with neighboring individuals through spatial and temporal avoidance (Zezulak and Schwab, 1979; Bailey, 1981; Plowman, 1997; Nielsen and Woolf, 2001; Chamberlain *et al.*, 2003).

Home range dispersion of male bobcats was larger than that of females and supports previous studies that reported larger home range (Hall and Newsom, 1976; Kitchings and Story, 1979; Litvaitis *et al.*, 1987; Conner, 1991; Lovallo and Anderson, 1996) and core area (Conner and Leopold, 1993; Plowman, 1997; Chamberlain *et al.*, 2003) sizes for male than female bobcats. In addition, male bobcats maintained relatively consistent patterns of home range central tendency between years, whereas females shifted home range central tendency. These observations provide further support for sex-specific hypotheses regarding bobcat space-use strategies at the home range level (Bailey, 1974; Anderson, 1987; Sandell, 1989; Conner *et al.*, 1999).

If male bobcat home ranges are larger than needed for meeting energy requirements (Anderson, 1987) and primarily influenced by the location of females (Bailey, 1981; Anderson, 1987; Conner and Leopold, 1993; Conner *et al.*, 1999; Chamberlain *et al.*, 2003), then exhibiting fidelity for large, non-shifting home ranges may be a beneficial space use strategy to assure access to adjoining females (Sandell, 1989), as was observed. Plowman (1997) suggested that male bobcats maximize breeding opportunities by overlapping portions of their core areas with those of neighboring females. We propose the shifting of core areas within relatively stationary home range areas by male bobcats was a spatial response to monitor and account for female spatial readjustments. This is further supported by observed similarities in core-area shift distances between male and female bobcats. Such space use patterns allow for continued defense of multiple females and increased breeding opportunities with minimal expenditure of energy. In addition, if female bobcats establish core areas to optimize access to prey resources, reacting to spatial readjustments of females could provide male bobcats access to pockets of abundant prey resources.

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