

INFLUENCE OF TIME-IN-RESIDENCE ON HOME RANGE AND HABITAT USE OF BOBCATS

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Abstract: Influence of time-in-residence on bobcat (*Lynx rufus*) home range size and habitat use is unknown. Therefore, we examined changes in home range size and habitat use as functions of monitoring duration for bobcats monitored ≥ 2 years in eastcentral Mississippi. We monitored 27 bobcats (5 M, 22 F) for a ≥ 2 -year period from 1 January 1989 to 31 December 1996. As duration of monitoring increased, changes in home range size were dependent on sex ($P = 0.07$). Male annual home ranges increased (previous year home range size = $1,534 \pm 212$ ha [$\bar{x} \pm SE$]) subsequent year home range size = $1,567 \pm 261$; $P = 0.08$, $n = 9$), whereas female annual home ranges decreased (previous year home range size = 781 ± 91 ha, subsequent year home range size = 640 ± 57 ; $P = 0.03$, $n = 36$) with time-in-residence. Habitat composition of female bobcat home ranges did not change over time ($P > 0.10$). Conversely, habitat composition of male home ranges seemed to change over time ($P = 0.08$). However, there were no univariate differences ($P > 0.10$) in male home range habitat composition as a function of time-in-residence. Interpretation of home range data without information concerning time-in-residence may be misleading.

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Reported bobcat home ranges in southeastern states ranged from 1.1 km² for females and 2.6 km² for males (Miller and Speake 1979) to 24.5 km² for females and 64.2 km² for males (Rucker et al. 1989). Male home ranges were generally 2–3 times larger than those of females (Hall and Newsome 1976, Buie et al. 1979, Miller and Speake 1979, Shiflet 1984, Whitaker et al. 1987). Anderson (1987) and Sandell (1989) stated that diversity, abundance, stability, and distribution of prey populations regulate female home range size, whereas male home range size is influenced by the number of mating opportunities. Variation in bobcat habitat use also has been ascribed to differences in habitat-specific prey abundance (Hall and Newsom 1976, Kitchings and Story 1978, Heller and Fendley 1982, Knowles 1985, Rucker et al. 1989, Knick 1990, Conner et al. 1992).

Few studies have examined the role of experience (time-in-residence) regarding its effect

on bobcat ecology, although experience does influence bobcat diet (Fritts and Sealander 1978, Whittle 1979, Towell 1982, Litvaitis et al. 1984). Additionally, no research has been conducted that examines effect of experience on bobcat home ranges or habitat use. This lack of research is due, perhaps, to a lack of long-term bobcat research projects. Therefore, we investigated influence of time-in-residence on home range size and habitat use of bobcats.

STUDY AREA

We selected 2 study areas with different forest management philosophies and habitat characteristics. One study area was the 142-km² Tallahala Wildlife Management Area (TWMA) located within Bienville National Forest, Mississippi. Mean annual temperature was 18°C, and annual precipitation averaged 152 cm (Carraway 1990). Pine (*Pinus* spp.) stands ($\geq 70\%$ pine dominated with mean diameter at breast height [dbh] > 5.0 cm) composed 46% of the study area. Loblolly pine (*P. taeda*) was the dominant species, with shortleaf pine (*P. echinata*) and longleaf pine (*P. palustris*) occurring in scattered patches. Approximately 29% of the area was in sapling stands (mean dbh ≤ 5 cm). Sapling stands averaged 13 ha in size and rarely exceeded 20 ha. Bottomland hardwoods, locat-

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ed primarily in riparian zones along major drainages, accounted for 21% of the area. Approximately 4% of the area was in agriculture. Pines were regenerated by clearcutting, followed by site preparation and planting or seed-tree methodologies. Average rotation age for pine stands was 80 years. Hardwood stands were regenerated via coppice management or by the shelterwood method. Hardwood clearcutting was prohibited.

The second study area consisted of 80 km² owned by Georgia Pacific Corporation (GP). The GP study area was located in Newton and Jasper counties, Mississippi, which are adjacent to TWMA. Because the GP area is adjacent to TWMA, weather patterns between areas were similar. Pine stands covered 60% of the area. However, 88% of pine stands on GP were <33 cm dbh (as opposed to 18% on TWMA). Sapling (20%), hardwood (12%), and agriculture (8%) composed the remainder of the study area. The land was managed primarily for timber production, and stands were regenerated by clearcutting and planting. Sapling stands >100 ha were common. Average rotation age of pine stands was 35 years.

METHODS

Capture and Monitoring

We captured bobcats with Victor soft-catch traps (Woodstream, Lititz, Pennsylvania, USA) during winters (7 Jan–15 Mar), 1989–96. Each year, we attempted to capture all bobcats on the study areas. Following capture, bobcats were netted and drugged with ketamine hydrochloride (15 mg/kg body mass). Bobcats were weighed, standard measurements were taken, and ear tags attached. We separated bobcats into 3 age classes (kitten: <1.0 yr; subadult: 1–2 yr; adult: >2 yr) based on tooth eruption, tooth staining and wear, body size, pelage characteristics, teat condition on females, and scrotum size of males (Crowe 1975). We fitted all adult females with a radiocollar (Advanced Telemetry Systems, Isanti, Minnesota, USA, and Wildlife Materials, Carbondale, Illinois, USA). We also radiotagged adult males captured in interior portions of our study areas. We monitored bobcats overnight to assess recovery, and we released them at the capture site. We allowed radiotagged animals 1 week to recover from capture before we initiated radiotracking. This research was conducted under the auspices

of Mississippi State University Institutional Animal Care and Use Committee animal use protocol 93-032.

We monitored bobcats with a TRX-1000S receiver and a hand-held 3-element Yagi antenna (Wildlife Materials, Carbondale, Illinois, USA). We determined locations by triangulation from fixed points within the study area (Cochran 1980, Kenward 1987, White and Garrott 1990), with ≥ 3 azimuths recorded to minimize error. To decrease error associated with animal movement, we allowed a maximum of 15 min between azimuths (\bar{x} = approx 4 min). To reduce serial correlation of animal locations, we maintained a minimum of 12 hr between locations of an individual animal. We performed telemetry sampling equally throughout the diel period. Only bobcats monitored for ≥ 2 years were used in analyses.

Telemetry accuracy tests indicated the standard deviation from true bearings was 6° ($n = 42$). Based on these results, a circle circumscribing the estimated location of a bobcat located 1 km from each telemetry station would have an approximate area of 3.5 ha. Approximately 90% of all telemetry bearings were taken <1 km from an animal. Because the smallest habitat unit delineated on the study areas was >10 ha and the smallest home range was >200 ha, telemetry accuracy was assumed sufficient for our analyses.

Data Screening

We formed a data pair for each consecutive 2-year period a bobcat was monitored. For example, if a bobcat was monitored during 1989, 1990, and 1991, there would be 2 pairs of data for that animal: 1989–90 and 1990–91.

Because period of monitoring and number of telemetry locations may affect home range size (White and Garrott 1990), we censored our data to ensure duration of monitoring and number of radio locations were equal for each member of a data pair. For example, if a bobcat was monitored from March to December of 1989 and all 12 months of 1990, we deleted data from January to February of 1990 to ensure equal duration of sampling within each year. After we standardized duration of monitoring for each data pair, we deleted random locations from 1 member of the data pair to ensure number of radio locations was equal for each dataset of the pair.

Home Range

We estimated home ranges via the 95% convex polygon method (Michner 1979, Bekoff and Mech 1984). By deleting the outermost 5% of locations, effects of extraterritorial forays (Knick 1990) on home range size were minimized. Home ranges were calculated with CALHOME (Kie et al. 1994). We calculated a home range for each dataset of the pair (1 for the first and 1 for the second period of monitoring).

We used Fisher's exact test in a 2×2 table (Zar 1996) to test if changes (increase or decrease) in home range size, relative to time in residence (first or second year monitored), were independent of sex. We used sign tests (Zar 1996) to determine if sex-specific annual home range sizes differed as a function of time-in-residence (e.g., first or second year monitored).

Habitat Use

Conner (1991) measured abundance of small mammals, white-tailed deer (*Odocoileus virginianus*), rabbits (*Sylvilagus* spp.), and tree squirrels (*Sciurus* spp.) in 41 forested stands on TWMA. Using data based on prey abundance within these stands, we delineated 4 habitat types: (1) sapling stands (forested with mean dbh ≤ 5 cm), (2) pine stands ($\geq 70\%$ pine and mean dbh > 5.0 cm), (3) hardwood stands ($> 70\%$ hardwood and mean dbh > 5.0 cm), and (4) agriculture (row crops or pasture). We transferred habitat types from aerial photography into a Geographical Information System via ARC/INFO (Environmental Systems Research Institute 1992).

We used the GENERATE command in ARC/INFO to convert bobcat home ranges into ARC/INFO coverages. We determined habitat composition of bobcat home ranges via the INTERSECT and TABLES subroutines of ARC/INFO (Environmental Systems Research Institute 1992).

We tested for differences in habitat composition of annual home ranges of each data pair with compositional analysis (Aitchison 1986, Aebischer et al. 1993). We constructed log-ratio differences for each habitat type of a data pair by using proportion of pine in the home range as the denominator. If a habitat did not exist in a home range, we used a value of 0.001 to represent the composition of that habitat (Aebischer et al. 1993). We tested the hypothesis that habitat composition of bobcat home ranges was

consistent from year-to-year by testing the null hypothesis that the mean vector of log-ratio differences was a vector of zeros. This test was performed with PROC GLM with the MANOVA option (SAS Institute 1992). All means are presented as mean \pm standard error. We considered a statistical test significant if $P \leq 0.10$.

RESULTS

We monitored bobcats from 1 January 1989 to 31 December 1996. Twenty-seven bobcats (5 M, 22 F) were monitored for ≥ 2 years, and 11 (2M, 9F) were monitored ≥ 3 years; therefore, there were 9 male and 36 female data pairs available for analysis. Because several bobcats had ≥ 2 data pairs, we performed each analysis twice. One set of analyses used all available data, whereas the second only used the first data pair for each animal. We excluded from habitat analyses those data pairs that contained home ranges off the study area (6 female data pairs).

When all available data were used, changes in annual home range size were dependent on sex (Fisher's exact test: $P = 0.02$). Previous-year female home ranges (781 ± 91 ha) were larger (median difference = 70.6 ha; sign test: $P = 0.03$, $n = 36$) than subsequent year home ranges (640 ± 57 ha). Previous-year male home ranges ($1,534 \pm 212$ ha) were smaller (median difference = 113.8 ha; sign test: $P = 0.08$, $n = 9$) than subsequent year home ranges ($1,567 \pm 261$ ha; Table 1). Habitat composition of female home ranges did not differ as a function of time-in-residence ($F_{3,27} = 1.02$, $P = 0.40$). Conversely, habitat composition of male home ranges seemed to change ($F_{3,6} = 3.66$, $P = 0.08$) as a function of time-in-residence. However, when habitat composition of male home ranges was examined in univariate space, we detected no differences ($P \geq 0.10$) in habitat composition of male bobcat home ranges (Tables 2, 3).

When we only used the first data pair for each bobcat, change in annual home range size also was dependent on sex (Fisher's exact test: $P = 0.05$). Previous-year female home ranges (843 ± 141) were larger (median difference = 70.6 ha; sign test: $P = 0.02$, $n = 22$) than subsequent year home ranges (617 ± 56). Although 4 of 5 male home ranges increased from first to second year monitored, previous-year male home ranges ($1,277 \pm 226$) did not differ (median difference = 113.8 ha; sign test: $P = 0.18$, $n = 5$) from subsequent year home ranges

Table 1. Home range size (ha), duration of monitoring, and number of radio locations for bobcats monitored for ≥ 2 consecutive years in eastcentral Mississippi, 1989–96.

Bobcat	Sex	Home range size (ha)							Dura- tion ^a	Loca- tions ^b	
		1989	1990	1991	1992	1993	1994	1995			1996
2	F	1,196	825							2–5	57
5	F	655	637							2–8	105
10	F	3,386	568							2–11	72
10	F		569	337						2–8	45
17	F			546	933					2–11	84
20	F		283	248						1–12	116
22	F		1,019	917						4–8	46
27	F			835	915					4–12	68
27	F				915	1,073				1–12	68
27	F					1,070	583			1–12	62
27	F						583	390		1–12	62
27	F							483	1,339	1–12	97
37	F				455	296				3–12	80
37	F					298	433			1–12	62
39	F				1,484	546				2–12	55
41	F				1,420	1,171				2–11	62
41	F					1,116	214			1–11	55
42	F				444	435				2–12	85
44	F				608	855				2–12	46
46	F				1,026	457				2–10	51
49	F					930	801			1–12	61
51	F					860	646			3–12	55
51	F						665	949		3–12	60
51	F							1,068	1,594	1–12	95
58	F					423	594			2–12	59
58	F						531	344		1–12	54
58	F							344	339	1–12	54
60	F					779	839			2–12	49
60	F						903	367		1–12	53
66	F					576	537			1–12	56
66	F						519	1,128		1–7	33
69	F						581	455		1–12	59
69	F						492	374		1–12	95
73	F						275	140		1–11	92
74	F						469	476		1–12	61
84	F						301	293		1–12	91
4	M	1,249	1,278							8–12	51
4	M				2,620	1,008				1–12	63
15	M		1,590	1,975						1–12	98
15	M			1,917	3,281					1–12	79
15	M				1,960	2,208				1–8	46
16	M		779	1,234						2–12	87
71	M						809	923		3–12	57
71	M							927	957	1–12	88
75	M						1,958	1,240		1–12	84

^a Months sampled during respective years (e.g., bobcat 5 was monitored Feb–Aug 1989 and 1990).

^b Number of telemetry locations used to generate each home range (e.g., each year during 1989 and 1990, 105 locations were used to calculate home range for bobcat 5).

(1,330 \pm 173; Table 1). Habitat composition of home ranges did not differ as a function of time-in-residence for either sex (M: $F_{3,2} = 1.31$, $P = 0.46$; F: $F_{3,15} = 0.63$, $P = 0.60$; Tables 2, 3).

We monitored 11 bobcats (2 M, 9 F) ≥ 3 consecutive years. Therefore, we graphically examined changes in annual home ranges to de-

termine if similar home range trends were evident for longer time periods. Of bobcats monitored for ≥ 3 years, 6 females had decreasing home ranges, whereas both male home ranges increased. Two females (no. 27, 66) shifted their home range during the last year of monitoring. This shift caused home range sizes, as calculated, to appear to increase during the last year of

Table 2. Mean log-ratio differences of habitat composition of bobcat home ranges in eastcentral Mississippi, 1989–96.

Habitat ^c	Log-ratio difference ^a				P(Log-ratio difference = 0) ^b	
	Female		Male		Female	Male
	\bar{X}	90% CI	\bar{X}	90% CI		
All data pairs ^d						
Sapling	0.01	0.42	0.27	0.44	0.96	0.30
Agriculture	0.09	0.53	-0.70	0.95	0.78	0.27
Hardwood	0.67	0.75	0.26	0.51	0.14	0.38
First data pair ^e						
Sapling	0.25	0.36	0.39	0.85	0.26	0.39
Agriculture	0.12	0.61	-0.25	1.62	0.74	0.75
Hardwood	0.18	0.54	0.46	0.70	0.55	0.27

^a Log-ratios calculated via home range composition of pine (dbh >5.0 cm and >70% pine) in the denominator. Differences calculated by subtracting the log-ratio of the second member from the log-ratio of the first member of a data pair.

^b P-values from univariate analysis of variance.

^c Sapling = forested with mean dbh <5.0 cm; Agriculture = land devoted to production of agricultural commodities; Hardwood = forested with mean dbh >5.0 cm and >70% hardwood.

^d Two home ranges derived for 2 consecutive years for a given animal constitute a data pair.

^e Analyzed via only the first data pair obtained for each animal.

monitoring. If the last year of monitoring was censored due to shift in home range, 8 of 9 female home ranges would have decreased during the period monitored (Figs. 1, 2).

DISCUSSION

There are relatively few long-term (>5 yr) bobcat research projects, likely because of financial costs and logistical concerns associated with long-term monitoring of a wide-ranging, relatively scarce carnivore. Our analytical approach represents the only such analysis of its kind and indicates experience to be an important factor in home range size of bobcats.

Researchers have hypothesized sex-specific differences in space-use strategies of bobcats (Bailey 1974, Anderson 1987, Sandell 1989). Our finding that changes in home range size were dependent on sex of the animal is further argument for sex-specific differences in ecolog-

ical strategies associated with bobcat home ranges. We believe both sexes use experience to increase fitness. Males optimize fitness by increasing home range size and maximizing breeding opportunities, whereas females optimize fitness by decreasing home range size and the energy associated with territory maintenance.

Home range size of male bobcats increased with time-in-residence, whereas habitat use remained relatively constant. Large male home ranges allow increased breeding opportunities (Bailey 1981, Anderson 1987, Sandell 1989), and well-established males (i.e., longer time-in-residence) may be in a position of dominance. If so, time-in-residence would allow dominant males to displace lesser males and maintain larger territories, thereby increasing breeding opportunities. Additionally, time-in-residence would allow males to discover areas that may offer breeding opportunities without risk of territorial infringement. If so, male home ranges could increase without appreciably increasing costs associated with territory maintenance. Because male home range size increased with time-in-residence, habitat composition of the home range became more similar to that of the study area. Therefore, we expected habitat composition of male home ranges to remain constant, as observed.

Home range size of female bobcats generally is accepted as being most strongly affected by habitat quality (see review by Anderson 1987). Our data indicate experience also may affect home range size of female bobcats. Increased

Table 3. Habitat composition^a of bobcat home ranges in east central Mississippi, 1989–96.

Habitat ^d	All data pairs ^b		First data pair ^c	
	Female	Male	Female	Male
Pine	50:46	53:54	53:47	47:50
Sapling	31:32	34:28	30:30	36:27
Agriculture	3:3	2:2	4:3	3:2
Hardwood	13:11	11:16	13:13	14:22

^a Ratio of percentage of habitat in home range during first year to percentage of habitat within home range during second year.

^b Two home ranges derived for 2 consecutive years for a given animal constitute a data pair.

^c Analyzed via only the first data pair obtained for each animal.

^d Pine = forested with mean dbh >5.0 cm and >70% pine; Sapling = forested with mean dbh <5.0 cm; Agriculture = land devoted to production of agricultural commodities; Hardwood = forested with mean dbh >5.0 cm and >70% hardwood.

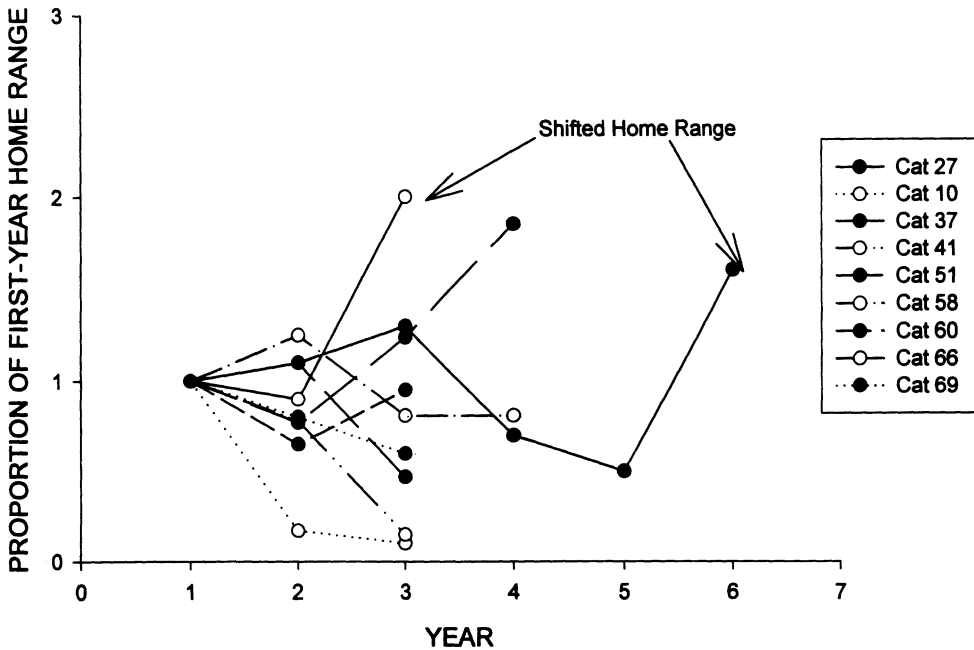


Fig. 1. Female bobcat annual home ranges reported as a proportion of the first-year home range for animals monitored ≥ 3 years in eastcentral Mississippi, 1989–96.

hunting skill and spatial learning (e.g., increased familiarity with the home range) represent possible mechanisms for the influence of experience on home ranges of female bobcats.

Increased hunting skill may explain the relation between female bobcat home range size and time-in-residence. As a female bobcat gains hunting experience, she may become more efficient at capturing larger prey often (Fritts and Sealander 1978, Whittle 1979, Towell 1982) and need to hunt less. Therefore, increased

hunting experience should lead to increased hunting success, less time spent searching for prey, decreased wandering, and a decrease in home range size. We hypothesize that as female bobcats improve hunting skills, time spent hunting will decrease and result in smaller home ranges due to decreased movements associated with hunting.

Spatial learning provides another possible explanation for decreased female home range size associated with time-in-residence. Animals benefit from knowing spatial locations of resources, even if resources at a specific location are not used (Goodenough et al. 1993). Lovallo and Anderson (1995) noted rapid home range shifts by female bobcats into areas that were vacated due to death of the previous resident female. We observed similar responses by female bobcats during our study. These movements indicated shifting females had spatial knowledge of the vacated home range. As time-in-residence increases, spatial learning may allow discovery of optimum routes between resource patches (e.g., prey-rich areas, den sites, refugia, etc.) and allow home range size to decrease. Additionally, spatial learning may allow female bobcats to optimize use of resource-rich patches while avoiding resource-poor areas. Such behavior should result in decreased home range size.

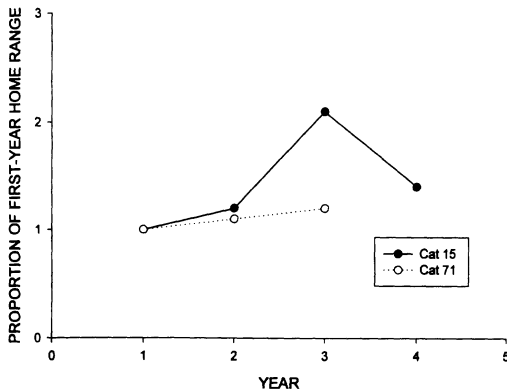


Fig. 2. Male bobcat annual home ranges reported as a proportion of the first-year home range for animals monitored ≥ 3 years in eastcentral Mississippi, 1989–96.

Although spatial learning occurs in female bobcats (Lovallo and Anderson 1995), it does not fully explain observed home range dynamics. If spatial learning were responsible for observed decreases in female bobcat home range size, habitat composition within the home range should reflect an increase in preferred habitat types as time-in-residence increases, but this was not observed. Therefore, relatively constant habitat composition within home ranges discounts spatial learning as the primary mechanism for observed home range dynamics of female bobcats.

Our data indicate bobcat home range dynamics are complex. Although we agree that prey abundance affects home range size of bobcats (Bailey 1981, Anderson 1987, Knick 1990), we believe time-in-residence also is important. Mechanisms including increased hunting skills, familiarity with the home range (i.e., spatial learning), and changes in habitat quality, social pressures, or both may act exclusively, or interactively, to influence home range size in bobcats. Unfortunately, there are few data available to determine relative influence of each of these mechanisms.

Lastly, research is needed to quantify various mechanisms that may affect bobcat home range dynamics. This research should focus on manipulative experiments to investigate the effect of each mechanism on bobcat home range size. Known-age bobcats released into novel areas could provide information concerning influence of age on home range size and habitat use. Radioisotope tagging (Conner and Labiski 1985) and collection of radioactive feces for diet analysis could be used in conjunction with radiotelemetry to relate home range size to diet and hunting skill. Increasing availability of prey-rich areas would allow investigation of the relation between prey abundance and home range size. Monitoring a population before and after a manipulated reduction could test effects of density on home range and habitat use. While number of animals monitored is very important in wildlife research, we should acknowledge importance of long-term monitoring of individual animals as a mechanism to more thoroughly understand ecological processes of the species in question.

MANAGEMENT IMPLICATIONS

Changes in home range size with increased time-in-residence provide some evidence for

age-specific spatial structure in bobcat populations, which may play a role regarding response of bobcat populations to harvest. Age structures that are skewed toward older animals should result in denser female populations, whereas males should become more dispersed. Because exploited bobcat populations favor younger animals (Fredrickson and Rice 1979, Lembeck and Gould 1979), harvested populations should have smaller male and larger female home ranges. Further, we predict recolonizing female bobcats to have larger home ranges than their predecessors, whereas recolonizing males should have smaller home ranges. Therefore, bobcat harvest may result in a numerical reduction in population size, a reduction in density of females, and an increased density of males associated with age- or experience-related spatial structure.

Few bobcat studies last longer than 2–3 years. In the absence of information concerning experience of monitored animals in the study area, these short-term studies may be misleading. For example, home range size has been used as an indicator of habitat quality for females of solitary felid species (Sandell 1989), including bobcats (Bailey 1974, Buie *et al.* 1979). However, if female home range size is affected by time in residence, inferences about habitat quality based on home range size may be biased by the age distribution of the sampled population. If the population is composed of young animals, home ranges may be large despite relatively good habitat quality. Conversely, if the population is composed of well-established residents, home ranges may be relatively small, although habitat may be marginal.

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