Bobcat Home Range Size Relative to Habitat Quality

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Abstract: Bobcat *(Lynx rufus)* home range is generally considered to be a function of habitat quality, but there have been few published studies that explicitly address this idea. We used empirically developed bobcat habitat models to predict habitat quality within bobcat home ranges on 2 study areas in central Mississippi. We then assessed the relationship between home range size and habitat quality. Habitat quality and variability of habitat quality were not ($P>0.10$) predictors of home range size. Moreover, habitat quality differed statistically ($P<0.01$), and habitat composition differed qualitatively between study areas, yet there were no differences ($P=0.14$) in bobcat home range size between study areas. We suggest that the effect of habitat quality on bobcat home range size may diminish as habitat quality increases, and we offer alternative hypotheses to explain bobcat home range size.

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Bobcat home ranges are highly variable, ranging from 1.1 km^2 and 2.6 km^2 (Miller and Speake 1978) to 24.5 km^2 and 64.2 km^2 (Rucker et al. 1989) for females and males, respectively. Male home ranges are generally 2 to 3 times larger than female home ranges (Hall and Newsome 1976, Buie et al. 1979, Miller and Speake 1978, Shiflet 1984, Whitaker et al. 1987). Differences in habitat are most often used to explain the wide variability in bobcat home range size (Anderson 1987).

Bobcat home range size is often considered inversely related to habitat quality with habitat quality determined by prey abundance (Bailey 1974, Buie et al. 1979, Sandell 1989, Knick 1990). Bailey (1974) suggested that decreases in bobcat prey populations may result in increased wandering of individual bobcats, increased home range size, and a breakdown in land tenure. However, there have been no published studies that explicitly explore the relationship between habitat quality and home range size. Therefore, our primary objective was to assess the relationship between habitat quality, as defined by empirically developed habitat models (Conner 1995), and bobcat home range size. To further investigate the relationship between habitat quality and bobcat home range size, we determined if bobcat home range sizes differed between 2 study areas that substantially differed regarding habitat composition.

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Methods

Study Areas

The study was conducted on 2 areas in east-central Mississippi. The first study area was the 142-km^2 Tallahala Wildlife Management Area (TWMA) within the Bienville National Forest. Mean annual temperature was 18 C and annual precipitation averaged 152 cm. Pine (*Pinus* spp.) stands ($\geq$70% pine dominated with mean dbh>5.0 cm) comprised 46% of the study area. Loblolly pine *(P. taeda)* was the dominant species, while shortleaf pine *(P. echinata)* and longleaf pine *(P. palustris)* occurred in scattered patches. Approximately 29% of the area was in sapling stands (i.e., forested with mean dbh$\leq$5 cm). Sapling stands averaged 13 ha in size and rarely exceeded 20 ha. Bottomland hardwoods accounted for 21% of the area and were located primarily in riparian zones along major drainages. Approximately 4% of the area was in agriculture. Pines were regenerated by clearcutting following site preparation and planting or seed-tree methodologies. Hardwood stands were regenerated using coppice management or by the shelterwood method, and hardwood cutting was prohibited.

The second study area consisted of 80-km^2 owned by The Timber Company (TC). The TC study area was located in Newton and Jasper counties adjacent to TWMA. Because of its close proximity to TWMA, weather patterns between the areas were similar. Pine stands covered 60% of the area. However, 88% of pine stands on TC were <33 cm dbh, as opposed to 18% on TWMA. Sapling (20%), hardwood (12%), and agriculture (8%) comprised the remainder of the study area. The land was managed primarily for wood fiber production and stands were regenerated by clearcutting and planting. Sapling stands >100 ha were common. Larger clearcuts, intensive pine management, absence of mature timber, and lack of hardwood stands on TC (as opposed to TWMA) allowed comparison of bobcat ecology between 2 different forest management regimes.

Bobcat Capture and Monitoring

We captured bobcats using Victor Soft-catch traps (Woodstream Corp., Lititz, Pa.). Following capture, we netted bobcats and drugged them with ketamine hydrochloride (15mg/kg body mass). We took standard measurements and installed ear tattoos on all captured bobcats. We separated bobcats into 3 age classes (kitten <1.0 year.; sub-adult 1–2 years.; adult >2 years.) 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 radio transmitter (Advanced Telemetry Systems, Isanti, Minn.). We also radio-tagged adult males that were captured in study area interiors. We monitored bobcats overnight to assess recovery then released them at the capture site. We allowed radio-tagged bobcats 1 week to recover from capture before we began radio-tracking. We trapped bobcats during winters (7 Jan–15 Mar) of 1989–1992. Each year, we attempted to capture all bobcats on the study areas. We tracked bobcats equally throughout the diel period. Only those bobcats having ≥50 telemetry locations/year were used in the analyses.

We monitored bobcats using a TRX-1000S receiver and a hand-held 3-element Yagi antenna (Wildl. Materials Inc., Carbondale, Ill.). We determined locations by triangulation from fixed points within both study areas (Cochran 1980, Kenward 1987, White and Garrott 1990). We often recorded >3 azimuths to minimize erroneous locations. To decrease error associated with bobcat movement, we allowed ≤15 minutes between azimuths. We converted azimuths to coordinates using TELEBASE (Wynn et al. 1990).

Telemetry accuracy tests indicated that the standard deviation from true bearings 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. This study was conducted under Institutional Animal Care and Use Protocol 93–032 of Mississippi State University.

Habitat Model Development

We developed habitat models using variables (Table 1) obtained from a GIS of the study areas. We used stepwise logistic regression as the statistical tool to develop the habitat models. We calculated posterior probabilities (i.e., probability of bobcat use) from the final logistic regression models as a habitat suitability index (HSI, Brennan et al. 1986) for bobcats. Because male and female bobcats select habitat differently (Bailey 1981, Sandell 1989), we developed separate models for each sex. Conner (1995) and Conner and Leopold (1998) provide a complete description of model development.

Home Range and Habitat Quality

We determined annual bobcat home ranges using the 95% convex polygon method (Michner 1979, Bekoff and Mech 1984). We calculated the mean arithmatic center of bobcat locations using a FORTRAN program (L.M. Conner, unpubl. data). Maximum distance from any bobcat radio-location to the mean arithmatic center also was determined using this program. This distance and mean center were used to construct a circle around all radio-locations for each bobcat using the ARC/INFO GENERATE command (Environ. Systems Res. Inst. [ESRI] 1992). We defined this circle as an availability circle because we assumed this area represented the available habitat in which the bobcat could establish a home range.

The ARC/INFO RAND function (ESRI 1992) was used to generate 10,000 and

Table 1. Variables used to develop bobcat habitat model on Tallahala Wildlife Management and The Timber Company (TC) land holdings in east-central Mississippi, 1989–1993. Habitat characteristics determined using GIS technology. Taken from Conner (1995).

Variable name	Description
TYPE	Forest type index (non-forested, pine, or hardwood)
COND	Stand condition (non-forested, sapling, pole, pulp and sawtimber)
EDGE	Distance[a] to edge
SAP	Distance to nearest sapling stand
PINE	Distance to nearest non-sapling pine stand
HWD	Distance to nearest non-sapling hardwood stand
RD	Distance to nearest road
RD1	Distance to nearest paved road
RD2	Distance to nearest gravel road
RD3	Distance to nearest maintenance road
CRK	Distance to nearest creek
CRK1	Distance to nearest primary creek
CRK2	Distance to nearest ephemeral creek
ELEV	Elevation (class)
SLOPE	Slope (8 equal classes 0°–90°)

[a] All distances measured in km

Table 2. Logistic regression coefficients of bobcat suitability index models developed on the Tallahala Wildlife Management Area and The Timber Company land holdings in east-central Mississippi. Taken from Conner (1995).

Parameter[a]	Coefficient (β_i)	$P(\beta_i = 0)$
Females		
SLOPE	0.53	<0.001
RD1	–0.22	<0.001
RD3	–1.33	<0.001
CRK1	0.30	0.001
COND	–0.35	<0.001
Constant	1.05	<0.001
Males		
RD3	–1.16	<0.001
COND	–0.30	0.001
Constant	2.24	<0.001

[a] SLOPE = 8 equal slope classes ranging from 0°–90°, RD1 = distance to paved road, RD3 = distance to maintenance road, CRK1 = distance to primary creek, COND = stand condition class (non-forested, sapling, pole, pulp, and sawtimber)

6,000 random points on TWMA and TC, respectively. Points falling within availability circles were then extracted using the ARC/INFO INTERSECT command (ESRI 1992). We calculated habitat quality at each extracted point using our HSI models (Table 2). Because models were developed using the same study animals used in this study, we assumed that our habitat models were at least correlated with habitat quality even if the models would not generalize well to other areas (Verbyla 1986, Verbyla and Litvaitis 1989). These HSI values were then used to calculate a mean HSI score for each availability circle. Stein's 2-stage sampling procedure (Steel and Torrie 1980) was used post-priori to ensure that there was ≥90% probability that the estimated mean HSI was within 10% of the true mean HSI (i.e., μ) for each availability circle.

Home range size was regressed against HSI scores, HSI standard deviations, bobcat sex (as a dummy variable) and all possible 2-way interactions using stepwise regression analysis. Significant ($P \leq 0.10$) regression coefficients were indicative of a relationship between a given dependent and independent variable. A Shapiro-Wilk's W was calculated to assess normality of residuals (SAS 1992). Residuals were plotted against predicted values to determine if data transformations were necessary (Kleinbaum et al. 1987, Neter et al. 1990).

To further assess any relationship between home range size and habitat quality we determined if HSI scores and bobcat home range sizes differed between study areas. We used mean HSI scores to determine if there were differences in habitat quality between study areas. Because separate HSI models were developed for each sex, sex-specific comparisons would be meaningless. However, because there was a greater proportion of monitored male bobcats on TWMA (41%) than on TC (23%), sex was included in analysis to partition variance from the error term. This analysis was performed using a 2-way ANOVA on rank transformed data (Conover and Iman 1981, Zar 1984). We tested for differences in home range size between study areas while controlling for differences between sexes and among years within a 3-way ANOVA on rank transformed data (Conover and Iman 1981, Zar 1984).

Results

There were 42 bobcat-years (15 male and 27 female) available for analysis (Table 3). Because a tornado drastically altered habitat on TWMA during November 1992, TWMA bobcats monitored after this period were excluded from analysis.

Stein's 2-stage sampling procedure indicated that the level of sampling intensity was adequate for all availability circles. A log-transformation of the home range was needed to meet regression assumptions. Stepwise regression of the log of home range size on independent variables indicated sex as the only significant variate ($P=0.01$; $r^2=0.12$).

Habitat suitability scores within availability circles averaged 0.63±0.01 ($\bar{x}\pm$SE). An analysis of HSI values between study areas indicated a mean HSI within availability circles on TC (0.70±0.01 was greater ($P>0.01$) than on TWMA (0.60±0.01). There were no significant 2-way interactions ($P>0.10$) regarding

Table 3. Number of male and female bobcats monitored using radio-telemetry on Tallahala Wildlife Management Area (TWMA) and The Timber Company (TC) landholdings in east-central Mississippi, 1989–1993.

	TWMA			TC		
Year	*M*	*F*	*Total*	*M*	*F*	*Total*
1989	3[a]	3	6	0	0	0
1990	4	6	10	0	0	0
1991	2	4	6	0	0	0
1992	3	4	7	2	5	7
1993	0	0	0	1	5	6
Total	12	17	29	3	10	13

a. Numbers reflect the number of individuals having ≥50 telemetry locations during the calendar year.

analysis of bobcat home range size. Annual home range sizes (1515±235 ha; $\bar{x}$±SE) did not differ (*P*=0.23) among years. Male home range sizes (2020±423 ha) were larger (*P*=0.03) than females (1234±272 ha). Bobcat home range sizes were similar (*P*=0.14) on TWMA (1692±291 ha) and TC (1119±388 ha).

Discussion

We found no relationship between habitat quality and home range size of bobcats. This may have been the result of invalid HSI models. However, HSI models will generally perform better on animals used to develop the model (Verbyla 1986, Verbyla and Litvaitis 1989), as is the case here. Therefore, even if an HSI generalizes poorly, it should at least be correlated with habitat quality on study areas used for model development. The observation that HSI differed statistically and habitat composition differed qualitatively between study areas, while bobcat home range sizes were similar on the 2 study areas, provided some evidence that home range size of Mississippi bobcats may be somewhat independent of habitat. However, we are uncertain as to whether a difference in HSI of 0.1 between study areas represents a biological difference in habitat quality. Given the above caveats and the variability of home range size observed during our study, our inferences concerning the relationship between home range size and habitat quality should be interpreted with caution.

Unfortunately, indices of prey abundance were not obtained in a consistent manner during the study. Therefore, the lack of a relationship between habitat quality and home range size was based on vegetation and physical habitat attributes rather than actual prey abundance. However, prey sampling conducted by Conner (1991) indicated that variables associated with high HSI values were also associated with prey abundance (e.g., sapling stands were predicted as an important habitat feature, and sapling stands had the highest prey abundance).

Perhaps the best evidence that bobcat home range size is a function of habitat quality can be found in comparing research of Marshall and Jenkins (1966) to that of

Buie et al. (1979). Bobcat home range sizes on the Savannah River Plant complex on South Carolina increased between 1966 (Marshall and Jenkins 1966) and 1978 (Buie et al. 1979). During this period, early successional habitats (e.g., old field and pastures) were converted to pine stands. As the original area became forested, prey biomass decreased, suggesting bobcat home range size to be a function of prey abundance (Buie et al. 1979). Additionally, Knick (1990) found that bobcat home range sizes increased and bobcat density decreased during a period of prey decline in Idaho. From this observation, Knick (1990) concluded that prey abundance dictated bobcat home range size and density. Interestingly, both of these studies dealt with habitat conditions that deteriorated over time. Although it may appear intuitive to extrapolate these results to the opposite scenario, (i.e., increasing habitat quality should result in reduced bobcat home range sizes), our data indicate that this extrapolation may not be valid.

Obviously, bobcats cannot survive in the absence of prey. When prey fall below some critical availability, it is intuitive that bobcat mortality or emigration must occur. However, if prey populations do not crash, bobcats may maintain larger home ranges than needed for meeting nutritional needs. Indeed, the tendency for male bobcats to maintain larger home ranges than that of females has historically been explained without invoking nutritional needs (Buie et al. 1979, Anderson 1987, Sandell 1989, Conner et al. 1992). We suggest that female bobcats also may maintain larger home ranges than required to meet nutritional demands.

When prey resources are not limiting, home range size may be influenced by density rather than habitat quality. Home range size of solitary carnivores is highly correlated with density (Sandell 1989). However, causality of this relationship has not been adequately documented. Indeed, Lovallo and Anderson (1995) observed an increase in home range size of a female bobcat when an adjacent female was removed; indicating home range size may be a function of density, rather than density being a function of home range size. If this is the case, it would be impossible to predict home range size solely as a function of habitat variables.

We suggest that when habitat quality is low, bobcat home range sizes are related to habitat quality as proposed by Buie et al. (1979) and Knick (1990). However, we also suggest that as habitat quality increases above some threshold, bobcat home range sizes should then become less dependent on habitat quality and more influenced by other features such as opportunity for breeding, diversification of potential prey and foraging patches, density, or other factors.

Management Implications and Future Research

We believe that small bobcat home ranges are indicative of good habitat. However, we do not believe that large bobcat home ranges necessarily indicate poor habitat because bobcats may use larger home ranges than required for survival and reproduction—this may be particularly important to consider when dealing with harvested populations. Thus, short-term studies of bobcat home range may be misleading if used to provide insight into habitat quality. Short-term studies may be especially misleading if there are no historical indices of bobcat density, no historical record of number of bobcats harvested, or no concurrent estimates of prey abundance.

It seems unlikely that the removal of a bobcat could result in decreased habitat quality of surrounding bobcats. In fact, by removing an adjacent animal, habitat quality could increase for remaining animals if habitat quality is density dependent. Anderson (1988) performed an experiment to test the effect of male removal on the space use patterns of surrounding bobcats. When a male cat was removed, adjacent animals quickly filled in the "void" left by the removed animal. Similar experiments should be performed with female bobcats to determine the relationship between home range size of female bobcats and habitat quality. Such an experiment would require home range estimation followed by removal of a portion of the population and subsequent home range estimation of remaining bobcats. If home ranges of remaining bobcats increase, this would provide evidence that home range size is at least partially influenced by density. In the absence of controlled experimentation, some information could be provided by reanalysis of existing data with special emphasis on home range estimation of bobcats before and after known mortality events.

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