Bobcat Habitat Use at Multiple Spatial Scales

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Abstract: Habitat use occurs at several spatial scales; however, bobcat (*Felis rufus*) habitat use has not been investigated at multiple scales. Additionally, sex-specific differences in bobcat habitat use have been hypothesized but not tested. Therefore, we investigated habitat use of 30 bobcats (9 males, 21 females) from 1 January 1989 to 31 December 1993 on 2 study areas in east-central Mississippi. We investigated bobcat habitat use at 2 spatial scales: habitat use within the home range and habitat composition of the home range relative to habitat composition of the study area. We did not detect differences ($P > 0.10$) in bobcat habitat use among sexes or study areas for either spatial scale. An empirical example of the importance of assessing habitat use at different spatial scales was discovered. Sapling and pine stands were preferred ($P < 0.10$) habitats when habitat compositions of home ranges were compared to study area compositions. However, when habitat use was compared to habitat availability within the home range, pine sapling was preferred over pine ($P < 0.001$), while remaining habitat rankings were equivalent ($P > 0.10$). Intensity of forest management did not affect bobcat habitat use.

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Variation in bobcat habitat use (Hall and Newsome 1976, Kitchings and Story 1978, Lancia et al. 1982, Heller and Fendley 1982, Rucker et al. 1989, Conner et al. 1992, Conner and Leopold 1993) has been ascribed to habitat-specific prey abundance (Bailey 1979, Knowles 1985, Litvaitis 1985, Knick 1990, Conner et al. 1992, Conner and Leopold 1993). Also, it is generally accepted that male bobcats are more habitat generalists than females (Bailey 1979, Anderson 1987, Sandell 1989). However, this latter hypothesis has not been tested, although Rolley and Ward (1985) found differences between sexes for seasonal habitat use without correction for habitat availability.

Within the geographical range of a species, an animal selects an area to establish a home range (HR). Individual patches within a HR are then used to meet specific needs. Lastly, procurement of resources occurs within patches (Johnson 1980). Although Johnson's (1980) paper is well known among wildlife biologists, few studies

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have addressed different hierarchies when assessing habitat use. Our objectives were to assess the relationship between forest management intensity and bobcat habitat use at 2 different spatial scales and to test for sex-specific differences in bobcat habitat use. We also determined a relative ranking of bobcat habitat preferences for each hierarchy.

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Methods

Study Areas

The study was conducted on 2 areas in east-central Mississippi. One study area was the 142-km^2 Tallahala Wildlife Management Area (TWMA) located within the Bienville National Forest. Mean annual temperature was 18 C and annual precipitation averaged 152 cm. Pine (*Pinus* spp.) stands (≥70% pine dominated with mean dbh > 5.0 cm) comprised 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 and rarely exceeded 20 ha. Bottomland hardwoods, located 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 clear-cutting followed by site preparation and planting or seed-tree methodologies. Average rotation age for pine stands was 80 years. Hardwood stands were regenerated using coppice management or by the shelterwood method. Hardwood clearcutting was prohibited.

The second study area consisted of 80-km^2 owned by Georgia Pacific Corporation (GP). The GP study area was located in Newton and Jasper counties adjacent to TWMA. Because of its close proximity 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%) comprised 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. Larger clearcuts, intensive pine management, absence of mature timber, and lack of hardwood stands on GP (as opposed to TWMA) allowed comparison of bobcat ecology between 2 different forest management regimes.

Bobcat Capture and Monitoring

Bobcats were captured using Victor Soft-catch traps (Woodstream Corp., Lititz, Pa.) during winters (7 Jan–15 Mar) 1989–1992. 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 installed. Bobcats were separated 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). All adult females were fitted with a radio-collar (Wildl. Materials Inc., Carbondale, Ill.). Selected adult males (animals captured in study area interiors) also were radio-tagged. Bobcats were monitored overnight to assess recovery, then released at the capture site. Transmittered animals were allowed 1 week to recover from capture before radio-tracking was initiated.

Bobcats were monitored 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 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, a maximum of 15 minutes was allowed between azimuths. To reduce serial correlation of animal locations, a minimum of 24 hours was allowed between locations of an individual animal. Telemetry sampling was performed equally throughout the diel period. Only bobcats having ≥50 telemetry locations were used in habitat 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, telemetry accuracy was assumed sufficient to assess habitat use.

Habitat Use

We examined habitat use with compositional analysis (CA) (Aitchison 1986, Aebischer et al. 1993), which circumvents many problems associated with resource selection studies. First, CA uses the animal as the sampling unit (Kenward 1992).

Second, resource use data typically comprise a composition (percentage data which sums to unity), which leads to non-independence of data. By using log-ratio transformations, percentage use of habitats becomes statistically independent (Aitchison 1986). Third, no other published resource use technique allows for between-group comparisons (e.g., sex-specific habitat use) while correcting for resource availability. Additionally, CA allows examining resource use of an organism at different hierarchies of use and availability (Johnson 1980). Finally, the technique allows for a relative ranking of habitat preference (Aebischer et al. 1993).

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. Abundance of these common bobcat prey items did not differ significantly ($P > 0.05$) between pine regeneration stands (stands with dbh < 1 cm; $N = 9$) and pine pole stands (1 cm ≤ dbh ≤5 cm; $N = 16$). However, these stands did differ significantly ($P < 0.05$) with respect to prey abundance from stands comprised of larger trees ($N = 16$). Subsequently, 4 habitat types were delineated. Pine sapling stands were defined as forested stands with a mean dbh ≤5 cm. Pine stands were defined as predominantly (≥70%) pine stands with a mean dbh >5.0 cm. Hardwood stands were defined as predominantly hardwood stands with a mean dbh >5.0 cm (hardwood stands <5.0 cm comprised <0.5% of study areas). Agriculture was defined as areas used for production of row crops or livestock. Habitat types were transferred from aerial photography into a geographical information system using ARC/INFO (Environ. Systems Res. Inst. [ESRI] 1992).

Habitat use was assessed at 2 spatial scales: habitat composition within the home range relative to habitat composition of the study area and habitat use relative to habitat composition within the home range. We determined habitat availability of study areas by determining habitat composition within a convex polygon that surrounded all bobcat locations. Habitat availability within annual home ranges was assessed by determining habitat composition within 95% convex polygon home ranges (Bekoff and Mech 1984). Percentage habitat use was determined as percentage of each bobcat's telemetry locations falling within a given habitat. Percentages of habitat use and availability were determined using the INTERSECT and TABLES subroutines of ARC/INFO (ESRI 1992).

All between-group hypothesis tests were performed using multivariate analysis of variance (MANOVA) with log-ratio differences as dependent variables (Aebischer et al. 1993). Independent variables were sex, study area, and their interactions. Multivariate analysis of variance (MANOVA) was also used to determine if habitat use differed from habitat availability. For this analysis, log-ratios of habitat use were compared to log-ratios of availability for each spatial scale.

Appropriate log-ratio differences were calculated for each bobcat using all possible numerator/denominator combinations. Habitat preferences were determined with an anti-symmetric matrix of log-ratio differences. This matrix tested relative habitat preferences in pairwise comparisons. A relative ranking of habitat preferences was derived based on the sign of the log-ratio differences or its associated t-statistic (Aebischer et al. 1993). Of N habitat types, only 1 habitat type had N-1 positive t-statistics

Table 1. Mean habitat use and habitat composition within 95% convex polygon home ranges of male ($N = 6$) and female ($N = 14$) bobcats monitored on Tallahala Wildlife Management Area in east-central Mississippi, 1989–1993.

	Proportion in home range		Proportional use	
Habitat type	Male	Female	Male	Female
Agriculture	0.02	0.05	0.04	0.06
Pine sapling	0.28	0.39	0.27	0.47
Pine	0.49	0.44	0.43	0.36
Hardwood	0.21	0.13	0.26	0.11

(the "best habitat") and only 1 habitat type had N-1 negative t-statistics (the "worst" habitat) (Aebischer et al. 1993). The log-ratio differences were tested to determine if they differed significantly from 0.0 (i.e., equal preference for the paired habitats) using a t-statistic. Statistical analyses were performed using SAS (SAS Inst. 1992).

Results

We determined habitat use of 30 bobcats (9 males, 21 females) from 1 January 1989 to 31 December 1993 on our study areas. Pine and pine sapling accounted for most (>80%) of the habitats used by bobcats (Tables 1,2). The interaction of sex and study area was not significant ($P > 0.10$), and there were no between-group (sex or study area) differences in habitat use ($P > 0.10$), regardless of spatial scale.

Habitat composition of bobcat home ranges differed from habitat composition of the study area ($P < 0.01$). The ranking matrix for this spatial scale indicated that bobcats preferred pine and pine sapling over agriculture and hardwood ($P < 0.05$), but there were no significant differences in preference for pine sapling over pine habitat ($P = 0.41$) or hardwood over agriculture ($P = 0.13$) (Table 3).

Bobcat habitat use within the home range differed from home range availability ($P = 0.01$). The ranking matrix for this spatial scale indicated that sapling stands were

Table 2. Mean habitat use and habitat composition within 95% convex polygon home ranges of male ($N = 3$) and female ($N = 7$) bobcats monitored on Georgia Pacific landholdings in east-central Mississippi, 1992–1993.

	Proportion in home range		Proportional use	
Habitat type	Male	Female	Male	Female
Agriculture	0.07	0.04	0.07	0.03
Pine sapling	0.19	0.26	0.23	0.29
Pine	0.61	0.58	0.58	0.54
Hardwood	0.13	0.12	0.12	0.14

Table 3. Ranking matrix used to rank habitat composition within 95% convex polygon home ranges of bobcats relative to habitat availability of the study area on Tallahala Wildlife Management Area and Georgia Pacific landholdings in east-central Mississippi, 1989–1993.

		Habitat types[a] (Denominator)			
		AG	SAP	PINE	HWD
	AG	—	–4.06[b] (<0.01)	–3.32 (<0.01)	–1.54 (<0.13)
Habitat types (Numerator)	SAP	4.06 (<0.01)	—	0.84 (0.41)	2.21 (<0.03)
	PINE	3.32 (<0.01)	–0.84 (0.41)	—	2.33 (0.03)
	HWD	1.54 (0.13)	–2.21 (<0.03)	–2.33 (0.03)	—

[a]AG = agriculture, SAP = pine sapling, PINE = pine stand, HWD = hardwood stand.

[b]Values are *t*-statistics of pairwise comparisons of numerator and denominator relative habitat use. A negative sign indicates the numerator was relatively avoided compared to the denominator. Associated *P*-values are in parentheses.

significantly preferred to pines ($P < 0.01$). There were no significant preferences among remaining habitat comparisons ($P > 0.10$) (Table 4).

Discussion

Habitat use of male bobcats may have been biased because male bobcats were only monitored if captured in the study area interior. However, this research design was incorporated to insure that larger ranges of male bobcats would not extend appreciably past the boundaries of our study areas. For any bias to have occurred, habitat composition of study area interiors must have differed from habitat composition of

Table 4. Ranking matrix used to rank habitat use relative to habitat availability within 95% convex polygon home ranges of bobcats on Tallahala Wildlife Management Area and Georgia Pacific landholdings in east-central Mississippi, 1989–1993.

		Habitat types[a] (Denominator)			
		AG	SAP	PINE	HWD
	AG	—	0.37[b] (0.71)	1.02 (0.31)	1.27 (0.21)
Habitat types (Numerator)	SAP	–0.37 (0.71)	—	3.69 (<0.01)	1.54 (0.14)
	PINE	–1.02 (0.31)	–3.69 (<0.01)	—	0.21 (0.83)
	HWD	–2.13 (0.21)	–1. 79 (0.13)	–0.00 (0.83)	—

[a]AG = agriculture, SAP = pine sapling, PINE = pine stand, HWD = hardwood stand.

[b]Values are *t*-statistics of pairwise comparisons of numerator and denominator relative habitat use. A negative sign indicates the numerator was relatively avoided compared to the denominator. Associated *P*-values are in parentheses.

study area exteriors. This was not the case. Further, to accommodate larger male home ranges, the study areas had to be expanded to allow for analysis of habitat data. Therefore, even though males were only monitored if captured in study area interiors, their larger home ranges were responsible for defining the perimeter of the study areas.

Bobcat males are postulated to be habitat generalists, relative to more selective females (Bailey 1981, Hamilton 1982, Rolley and Warde 1985, Sandell 1989, Conner 1991, Conner et al. 1992). However, this hypothesis has never been tested. If male bobcats are habitat generalists while female bobcats tend to be habitat specialists, there would have been a significant difference in habitat use between sexes. Habitat delineations employed in our analyses indicated bobcat males were no more general regarding habitat use than females.

Because bobcats are territorial (Hall and Newsome 1976, Anderson 1987, Sandell 1989), it would be logical to assume that spatial distribution of bobcats would constrain habitat composition of home ranges to equal that of study areas. However, habitat composition of bobcat home ranges differed from study area availability, leading to the possibility that territoriality plays a minor role in habitat use of bobcats. Intrasexual home range overlap, though slight, was documented on TWMA (Conner et al. 1992). Further, intersexual home range overlap in bobcats is common (Anderson 1987, Rucker et al. 1989, Sandell 1989). Additionally, there were areas that appeared to be devoid of resident bobcats. These voids were assumed by Conner et al. (1992) to be occupied by non-monitored bobcats. This assumption may have been incorrect. Home range overlap in areas of presumably good habitat coupled with voids in presumably poor habitat are the most likely cause for differences between home range habitat composition and habitat composition of study areas.

Based on analysis of habitat composition of the home range relative to habitat composition of the study area, pine sapling and pine were preferred over hardwood and agriculture. The prevailing explanation for differential habitat use among bobcats is prey abundance (Bailey 1979, Fuller et al. 1985, Knowles 1985, Litvaitis 1985, Boyle and Fendley 1987, Knick 1990). Pine sapling stands had significantly more bobcat prey than other available habitats (Conner 1991). Thus, the observed preference for sapling stands was consistent with a prey abundance hypothesis of differential habitat use (Bailey 1979, Fuller et al. 1985, Knowles 1985, Litvaitis 1985, Boyle and Fendley 1987, Knick 1990).

The preference of pine over hardwood and agriculture at a larger spatial scale is less clear, as pines were found by Conner (1991) to have the lowest prey abundance of all available habitats. Because the pine forest type only occurred in upland sites, use of mature pines may have been due to spatial relationships of pine sapling and pine stands. Pine sapling stands were usually surrounded by pine. When habitat use within bobcat home ranges was compared to habitat composition of home ranges, pine saplings were preferred over pine. We believe bobcats used pine sapling due to prey abundance, and that any preference for pine relative to study area availability was due to spatial association with pine sapling habitats.

When bobcat locations were compared to habitat availability within home ranges, agriculture had all positive t-statistics, while hardwood t-statistics were all negative. A literal interpretation would indicate that agriculture was most preferred and hardwood least preferred at this spatial scale. However, none of the *t*-statistics associated with agriculture or hardwood were significant. This is likely due to wide variation in use and availability of these habitat types. Since the pine sapling to pine comparison was the only significant comparison at this spatial scale, we feel that all other habitat types were roughly equivalent in terms of preference ranking.

Bobcat habitat use differed across spatial scales. Managers should be aware that spatial scale can make profound differences in management recommendations. For instance, had we only compared habitat composition of the home range to the composition of the study areas, we would have concluded that pine stands were equally valuable to pine sapling stands. By investigating at 2 spatial scales, we found that pine saplings were strongly preferred over pine within bobcat home ranges.

Management Implications

Bobcats are a top carnivore and a vital component of most terrestrial ecosystems in the United States. Additionally, the role of the bobcat as a predator of game animals is still poorly understood. In the past, bobcat pelts have ranked among the most valuable of North American furbearers (Anderson 1987). The bobcat's role in ecosystem function, impact on game species, and value as a furbearer necessitates management attention from wildlife biologists, especially when they exist in the absence of other larger carnivores such as mountain lions (*Felis concolor*) and wolves (*Canis lupus*). Additionally, there is evidence that predation may be managed by habitat manipulation (Leopold and Hurst 1994). If true, a thorough understanding of predator habitat needs should lead to habitat management recommendations which would seek to control predator-prey interactions.

Bobcat habitat use did not differ between study areas although these areas differed regarding forest management. While habitat manipulations have intuitive implications concerning bobcat ecology, our analysis indicated that different forest management practices on the 2 study areas had little effect on bobcat habitat use. On both areas, a preference for pine sapling was evident and bobcat prey were most abundant in pine sapling stands (Conner 1991). Timber harvests should benefit bobcats by creating pine sapling stands, which act as favorable habitats for bobcat prey (Miller and Getz 1977, Dueser and Shugart 1978, Yahner 1986, Medin and Booth 1989). Unfortunately, it would be financially unprofitable and ecologically unwise to keep large areas of forests in the sapling stage. Therefore, managers must strike a balance between timber production and bobcat prey.

As ecosystem management becomes increasingly popular, managers will need species to serve as reliable indicators of ecosystem health. Since bobcats are very closely tied to their prey, we suggest that bobcats would be excellent indicators of ecosystem health. Before this idea can be placed into practice, further research is needed to relate prey species abundance to bobcat diet, home range size, and density.

Bobcats cannot exist in the absence of prey. Likewise, there must exist some prey density threshold that enables a habitat patch to be used by bobcats. In forested ecosystems, prey density is largely influenced by forest management (Miller and Getz 1977, Dueser and Shugart 1978, Yahner 1986, Medin and Booth 1989). Research is needed to determine the relationship of forest management practices to prey abundance and bobcat habitat use. We believe that influences of habitat physiognomy as impacted by forest management would be of particular importance in understanding predator-prey-habitat relationships in forested ecosystems.

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