Wildl. Soc. Bull. 17:5–10, 1989

EFFECTS OF ROADS ON BLACK BEAR MOVEMENTS IN WESTERN NORTH CAROLINA

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Wildlife biologists frequently evaluate the effects of human development or disturbance on wildlife habitats and populations. Because wildlife-habitat relationships are complex, general guidelines for making such evaluations are scarce, and evaluation methods often must be case specific. While many evaluation procedures are objective, the identification of particular aspects of an ecological system that might be influenced by human development or disturbance is almost always a subjective process. In this paper we assess the reaction of black bears (*Ursus americanus*) to roads in the Pisgah National Forest of western North Carolina.

Roads have been implicated frequently as factors affecting black bear behavior and habitat quality in the southeastern United States. In areas open to hunting, bears avoid roads (Reiffenberger 1974, Hamilton 1978, Brown 1980, Villarrubia 1982). In contrast, in the Great Smoky Mountains National Park and the Blue Ridge Parkway, where hunting is prohibited and visitors seek to view wildlife, bears cause problems when attracted to roads by the presence of human food. The behavior of bears in response to roads is probably learned, and is linked to costs and benefits experienced and perceived by individual bears. Analysis of the effect of roads on bears should thus consider human uses of roads and habitat use by bears.

Animal movement patterns may be viewed as tactics that tend to optimize the efficiency of habitat exploitation subject to physical, ecological, and social constraints (Pyke 1981, Anderson 1983). The risk of mortality or predation has been incorporated as a constraint in habitat use models for several species (Milinski and Heller 1978, Sih 1980, Stamps 1983, Werner et al. 1983). If crossing a road increases the risk of mortality to a bear, the frequency of road crossing by an individual bear may be viewed as the result of a trade-off between efficient resource exploitation and risk of mortality.

We suggest that the primary effect of roads in bear habitat in western North Carolina is an increase in the vulnerability of bears to hunting. Hunting with the aid of dogs is traditional and popular in the southern Appalachian Mountains, and an extensive road system increases the efficiency of hunters. Hunters drive slowly along roads with "strike dogs" riding on the hood or in the bed of vehicles, searching for fresh bear scent. Thus, bears that frequently cross roads are most susceptible to being detected and killed by hunters. However, bears are killed on <20% of occasions that dogs pursue bear tracks (J. Beringer, Univ. of Tennessee, pers. commun.); thus, there appears to be ample opportunity for bears to learn to avoid roads.

Possible effects of road system development on bear population dynamics were explored by Bunnell and Tait (1977) and Brody and Stone (1987). Our study complements previous work by concentrating on the behavior of individual bears. We analyze the frequency of road crossings by bears. We assume that the encounter rate between humans and bears is a function of traffic volume (No. of vehicles per

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unit length of road per unit time) and road density (length of road per area of habitat). Bears can control the encounter rate through movement patterns.

Data used in our analyses were collected as part of a more general study of bear habitat use, and ideas for these analyses came after completion of fieldwork. Our purpose is to present a conceptual framework and analytical method for evaluating the relationship between roads and bear movements and to present tentative conclusions from an application of the method.

STUDY AREA

We studied a population of black bears in the Harmon Den and Twelve Mile Strip areas of Pisgah National Forest in Haywood County, North Carolina, during 1982–1983. Timber production and dispersed recreation were the primary land uses on the 11,400-ha area. Five thousand hectares were included in a state bear sanctuary; the remainder of the area was open to hunting for 9 weeks, split into 2 fall seasons. Twenty-three kilometers of Interstate 40 (I-40) roughly bisect the area. Not including I-40, there were 65 km of passable roads in the study area.

Roads in Harmon Den and the Twelve Mile Strip were classified by surface and access characteristics. We did not measure traffic levels directly during the study, but assumed that traffic was correlated with surface and access classifications. High speed traffic is heavy on I-40, a paved 4-lane divided highway. Other roads in the study area were unpaved. Approximately 40 km of gravel road, on which travel was not restricted, traversed the area. Traffic levels on these roads were well below the level on I-40, but were occasionally heavy, especially on summer weekends, during hunting seasons, or near active timber sales. Approximately 25 km of gravel or dirt roads that were closed by locked gates received much less traffic than the unrestricted roads; these roads were mainly collector roads for timber harvest operations. There were approximately 20 km of abandoned roads, which were still recognizable as roads but were not connected to the existing road system and received no motorized vehicle traffic. These 4 categories of roads provided a convenient structure for examining the relationship between road crossing frequency, relative traffic volume, and road density.

METHODS

Bears were captured in Aldrich foot snares and fitted with radio collars. We located collared animals 2–5 times/week between April and December using ground triangulation and, occasionally, aerial homing (Brody 1984). Collared bears that left the 114-km^2 defined study area were located infrequently.

We plotted seasonal home ranges of bears by using the convex polygon technique (Hayne 1949, Harestad 1981). Seasons were defined as summer (from den emergence to 1 Sep) and fall (from 1 Sep to den entrance) (Brody 1984). Road densities for each of the 4 types of roads in each seasonal home range were determined by overlaying the convex polygons on U.S. Forest Service transportation maps and measuring the length of roads inside home ranges. If parts of a home range fell outside the defined study area, we eliminated those parts from consideration and truncated the range boundaries to coincide with boundaries of the defined study area.

The road system was digitized from transportation maps, and telemetry locations used to construct each home range were plotted sequentially by computer. We tallied the number of times each line segment that connected successive locations crossed each of the 4 types of roads. Totals were considered to be the minimum number of times each bear crossed each type of road. We did not count line segments that fell entirely outside the defined study area.

The frequency that bears crossed each type of road was indexed by

$$F_{ijr} = X_{ijr}/D_{ijr} \quad (1)$$

where

F_{ijr} is the relative frequency index for bear i in season j to cross road type r,

X_{ijr} is the number of crossings by bear i in season j of road type r, and

D_{ijr} is the density of road type r in the home range of bear i in season j.

Overall significance of the influence of road type on the relative frequency index was tested with 2-way nonparametric analysis of variance (Conover 1980), with road types and individual bears as sources of variation. Pairwise comparisons of treatment effects were made using Mann-Whitney U-tests.

To examine the population-wide relationship between road crossing and road density, we compared frequency of road crossing by each bear to density of roads in its home range. We assumed that total number of crossings observed for a given bear in a particular season was positively related to number of telemetry locations, and converted the numbers of crossings per telemetry location for each seasonal range to indices of road crossing:

$$I_{ijr} = X_{ijr}/(N_{ij} - 1) \quad (2)$$

where

I_{ijr} is the road-crossing index for bear i in season j of road type r,

X_{ijr} is the minimum number of times bear i crossed road type r in season j, and

N_{ij} is the number of telemetry locations of bear i in season j.

The number of opportunities we had to observe bear i cross roads in season j is then $N_{ij} - 1$. We used nonparametric analysis of variance to test if the road-crossing index for each type of road varied by sex, season, or age class (juv = <3 yrs old vs. ad) of bears or whether the home range was inside or outside the bear sanctuary. Spearman rank correlation coefficients between road density and road-crossing index were calculated for each type of road. Then we used linear regression models to examine the relationship beween road density and road-crossing index for each type of road. Residual plots were examined to detect nonlinearity in relationships.

The frequency of road crossing by an animal moving randomly through a habitat in which roads are uniformly distributed is directly proportional to road density. A line describing this relationship has a positive slope related to the rate of movement, and passes through the origin as no roads are crossed when there are no roads in the habitat. If roads affect bear movements, we would expect a change in slope, intercept, or both, of the line describing the road-crossing/road-density relationship.

RESULTS

Radiotracking 17 bears yielded data that described 29 seasonal home ranges (Table 1). Eight of the 17 bears were killed by hunters during the study, 5 legally and 3 illegally. The illegally killed bears were killed inside the bear sanctuary during legal hunting seasons. One radio-collared bear that was not located frequently enough to be included in these analyses was killed in the sanctuary out of season.

There was a significant effect of road type (Friedman test, $\chi^2 = 52.0$, 2 df, $P < 0.001$) on the relative frequency with which bears crossed roads and no effect of individual bears (Friedman test, $\chi^2 = 37.0$, 16 df, $P = 0.11$). Mean ranks of relative frequency index, from least to greatest, were 1.1 for I-40, 2.6 for unrestricted roads, 2.9 for restricted roads, and 3.5 for abandoned roads, the inverse of ranks for traffic volume on these 4 types of roads. Differences implied by the mean ranks were significant among all pairs of roads ($P < 0.05$).

Radio-collared bears demonstrated a pronounced avoidance of I-40; only 3 bears crossed I-40 on a total of 5 occasions. I-40 intersected 13 seasonal ranges of 8 bears, but only near

Table 1. Number of telemetry locations, home range areas, road densities, and road-crossing indices for 17 black bears in Pisgah National Forest, North Carolina, 1982–1983.

Season		Abandoned roads						Restricted roads				Unrestricted roads			
		Area (ha)		RD[a]		RCI[b]		RD		RCI		RD		RCI	
Sex	n	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Summer															
Males (9 ranges)	280	2,831	1,330	1.01	0.73	0.68	0.52	1.45	0.15	0.64	0.15	1.01	0.22	0.30	0.06
Females (7 ranges)	373	1,141	245	0.92	0.29	0.76	0.19	1.61	0.29	0.36	0.14	1.34	0.25	0.24	0.06
Fall															
Males (5 ranges)	171	1,869	574	0.76	0.85	0.46	0.21	1.50	0.69	0.57	0.22	1.38	0.27	0.34	0.07
Females (8 ranges)	382	1,269	132	0.55	0.20	0.43	0.13	1.42	0.30	0.39	0.13	1.21	0.16	0.36	0.06

[a] RD = road density (km/km^2).
[b] RCI = road-crossing index (see Methods).

Table 2. Regression analyses of road-crossing index (see Methods) and road density (km/km^2) in home ranges of black bears for roads with different levels of traffic in Pisgah National Forest, North Carolina, 1982–1983.

Road type	Intercept	Slope	r^2
Abandoned (n = 29)	0.294 (P = 0.067)	0.430 (P < 0.001)	0.45
Restricted (n = 29)	0.124 (P = 0.28)	0.252 (P < 0.001)	0.38
Unrestricted (n = 29)	0.009 (P = 0.19)	0.184 (P < 0.001)	0.48

the edges of these home ranges. It is likely that intersections between I-40 and the home ranges were artifacts of the convex polygon method of determining home range boundaries and the circuitous route of I-40 through the study area. Avoidance of I-40 was probably related to high traffic levels; at least 2 uncollared bears were killed in collisions with vehicles on I-40 during the study. Because of the small number of bear crossings of I-40, this road was excluded from further statistical analyses.

There were no effects ($P > 0.05$) of sex, age, season, or sanctuary status on the road-crossing index for the other roads examined, and data from all home ranges were pooled for the subsequent analyses. Road-crossing index was correlated with road density for all road types (r_S = 0.65, 0.57, and 0.62 for abandoned, restricted, and unrestricted roads, respectively). Residuals of the regressions exhibited no obvious pattern, indicating that, within the range of road densities found in bear home ranges, the road-crossing/road-density relationship was essentially linear. The rather low r^2 values (Table 2) are indicative of a large amount of variation, implying, as expected, that other factors also affected the frequency of road crossing. Slopes of regression lines for abandoned roads and unrestricted roads were different ($P <$ 0.05), indicating that bears were more reluctant to cross roads with higher traffic volumes. That is, the frequency of road crossing increased with road density at a faster rate for unrestricted roads than for restricted roads, and faster still for abandoned roads.

None of the intercepts was different from 0 ($P > 0.05$), but again the exhibited trend was expected if the tendency to cross roads is inversely related to traffic level. However, the intercept of the relationship between crossings and density of abandoned roads may in fact be >0 (P = 0.067), implying an affinity for these abandoned roads; bears might be using them as travel corridors. Bears also might be attracted to food plants found in abundance on abandoned roads (Brody 1984).

DISCUSSION

Our data indicated a negative relationship between the relative frequency with which bears cross roads and traffic levels on roads. As road density or traffic level increased, the potential for bears to encounter human activity increased. More importantly, in a population subject to hunting by the methods typically used in the southern Appalachians, an increase in road density increases the potential for hunters to encounter bears. Hunter success rates are apparently low enough to provide individual bears with the opportunity to learn to associate roads with humans, and thus adopt movement patterns that tend to minimize encounters with humans.

If road avoidance is a learned behavior, older, more experienced bears should cross roads less frequently than younger bears. However, we did not detect an effect of age. Similarly, if roads are avoided because of the perceived risk associated with hunting, the frequency of road crossing should decrease with increased risk of being hunted. As bears are more vulnerable to hunting in the fall and outside the sanctuary, it was somewhat surprising that neither season nor sanctuary status showed any effect on the road-crossing index.

There are 2 possible causes for the lack of effect of sanctuary status. First, some hunting does occur in the sanctuary, so the risk in crossing roads may not be that much lower than outside the sanctuary (4 bears killed during the study were killed inside the sanctuary). Pursuits by hounds that begin outside the sanctuary may lead into and continue in the sanctuary. Also, raccoons (*Procyon lotor*) and opossums (*Didelphis virginiana*) are legally hunted inside the sanctuary using the same techniques as for bears. Second, only 7 of the seasonal home ranges were completely inside the sanctuary boundaries, so most bears had at least some experience with roads outside the sanctuary, and the distinction in sanctuary status is thus somewhat arbitrary.

The lack of effect of different seasons on the road-crossing index is the most difficult to explain, as the risk of mortality from hunting is much higher in the fall than in the summer. Garshelis and Pelton (1981), Brody (1984), Clevenger (1986), and many others have noted major seasonal changes in habitat use by bears in the southern Appalachians, and related these changes to seasonal shifts in diet. Garshelis and Pelton (1981), Carr (1983), and Clevenger (1986) described geographic shifts in location of seasonal ranges of individual bears in other areas of the southern Appalachians, but Brody (1984) suggested that habitat patchiness resulting from logging in Harmon Den led to seasonal changes in distribution of habitat use within many home ranges, unaccompanied by major changes in home range boundaries. It may be that efficient fall habitat exploitation tactics in Harmon Den required frequent road crossing despite increased risks.

The analysis of frequency indices showed a clear preference by individual bears to cross roads of lighter traffic than those carrying heavier traffic. These preferences at the individual level translate at the population level to a decrease in the slope of the road-crossing/road-density relationship with increasing traffic volume. Because the relationship is linear for all traffic levels, we suggest that bears do not alter their movement patterns with respect to road densities within their established home ranges, and that the response to road densities may be a geographical shift in the locations of the home ranges when road densities reach certain thresholds. Bears may be able to adjust movement patterns to minimize the risks associated with traffic as long as road densities remain relatively low. If such adjustment becomes inefficient at high road densities, the response may be to shift into areas of relatively low road density. The reluctance of bears to cross I-40 indicated that the threshold density for roads bearing that volume of traffic is extremely low, and suggested that most bears in the study area have established their home ranges in areas that do not include I-40. Such shifts would not be easily detected in telemetry data such as ours, gathered on a time scale that is short relative to the time scale of road development.

The long intervals between telemetry locations of individuals in our data preclude detection of more subtle reactions to road density, such as restricted use of areas of higher road density within a home range or the timing of road crossings. Additionally, we have not taken into account the geographical relationships between roads and different habitat types; differential use of habitat types by bears will obviously affect the relationship between road crossing and road density.

SUMMARY

Using telemetry data from 17 black bears in Pisgah National Forest, we investigated the frequency of road crossing by bears in relation to traffic volume and road density. Bears almost never crossed an interstate highway in the study area. Of the roads that bears did cross, roads of low traffic volume were crossed relatively more frequently than roads of higher traffic volume. Road-crossing frequency was not affected by age or sex of bears, season, or sanctuary status of the bears' home ranges. The road-crossing/road-density relationship was linear for all volumes of traffic, indicating that bears did not restrict their movements in reaction to road density within established home ranges. Bears may react to increases in road densities by shifting the locations of their home ranges to areas of lower road densities.

Acknowledgments.—This study was supported by the U.S. Forest Service, McIntyre-Stennis Project 39 of the Agricultural Experiment Station and Department of Forestry, Wildlife, and Fisheries, University of Tennessee, and the National Rifle Association. We thank L. L. Hillman, C. White, W. Champion, and J. M. Collins for providing field and logistical support. J. Litzau provided statistical advice. Comments from D. L. Garshelis, P. A. Abrams, and an anonymous reviewer greatly improved earlier versions of this manuscript.

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Received 19 June 1987.
Accepted 27 September 1988.