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THE EFFECTS OF ROADS ON SPACE USE AND MOVEMENTS OF BLACK BEARS IN EASTERN KENTUCKY

Rebekah A. Jensen
University of Kentucky, rebekah.jensen@uky.edu

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ABSTRACT OF THESIS

THE EFFECTS OF ROADS ON SPACE USE AND MOVEMENTS OF BLACK BEARS IN EASTERN KENTUCKY

Kentucky, USA, is the site of recent natural recolonization by the American black bear (*Ursus americanus*); however, bears are rarely observed outside the Cumberland Mountains along the state's southeastern border. I examined the influence of roads in constraining the distribution of this population by altering animal space use and movement. I identified patterns of road avoidance and road crossing using data from Global Positioning System collars worn by 28 adult bears (16M, 12F), and described road mortality trends using 27 roadkill events. Bears avoided roads at the home range and landscape scale, primarily crossed low-traffic roads, and crossed in sites that minimized detection by humans. Males displayed more evidence of road avoidance than females, but females crossed roads more selectively than males. Bears were most often killed on high to moderate traffic roads, and in areas less forested than expected. Roadkill and road crossing sites bore different attributes. The results of my study support previous findings that space use near roads and road crossing reflect a tradeoff between the risks of road mortality and human harassment, and the benefits of access to habitat, mates, and anthropogenic food. Road-mediated restriction of black bear space use and movement is indicated.

KEYWORDS: Black bear, connectivity, Kentucky, road, *Ursus americanus*

Rebekah A. Jensen

December 10, 2009

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By

Rebekah Ann Jensen

Dr. John J. Cox
Co-Director of Thesis

Dr. Michael J. Lacki
Co-Director of Thesis

Dr. David B. Wagner
Director of Graduate Studies

December 10, 2009

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THESIS

Rebekah Ann Jensen

The Graduate School

University of Kentucky

2009

THE EFFECTS OF ROADS ON SPACE USE AND MOVEMENTS OF BLACK BEARS IN EASTERN KENTUCKY

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Agriculture
at the University of Kentucky

By

Rebekah Ann Jensen

Lexington, Kentucky

Co-Directors: Dr. John J. Cox, Adjunct Assistant Professor of Wildlife and Conservation Biology
and Dr. Michael J. Lacki, Professor of Forestry

Lexington, Kentucky

2009

I dedicate my thesis to the late Dr. David S. Maehr, whose blustery bearlike zest for wildlife conservation and living continues to inspire me.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

People rely on roads for personal transportation, distribution of goods and services, and support of local and national economies (Forman et al. 2003). However, roads greatly impact the terrestrial and aquatic ecosystems they traverse. Ecological effects of roads are not just limited to the pavement and verges, but are evident in the surrounding "road-effect zones" (Forman and Alexander 1998). While roads cover ca. 1% of the United States landscape (National Research Council 1997), their ecological effects generally extend 100 m or more from the pavement, impacting 19% of the total area of the U.S. (Forman 2000).

Trombulak and Frissell (2000) identified 7 major ecological effects of roads, both along rights-of-way and in road-effect zones: 1) mortality from collision with vehicles, 2) mortality from road construction, 3) modification of animal behavior, 4) alteration of the physical environment, 5) alteration of the chemical environment, 6) spread of exotic species, and 7) increased human access to formerly remote areas. Associated with several of the above categories is the subdivision of large habitat patches by roads and road-effect zones into smaller, more isolated elements (Saunders et al. 2002). I refer to habitat fragmentation as an eighth major ecological effect of roads.

Nearly all terrestrial wildlife species are susceptible to mortality from vehicle collisions (Trombulak and Frissell 2000). Slow-moving or sessile animals found in the footprint of a road at the time of construction may be killed by road-building activities (Trombulak and Frissell 2000). Roads modify animal behavior by forcing shifts in home ranges (Brody and Pelton 1989), and by altering movement patterns (Whittington et al. 2004), reproductive success, and physiological states (Trombulak and Frissell 2000). Disruptions in the physical environment such as increased warmth along roads can encourage the aggregation of basking reptiles, making them more at risk for vehicle-caused mortality (Rosen and Lowe 1994). Hydrological effects such as erosion and stream sedimentation can be detrimental to fishes (Barton 1977). Roads may alter the chemical environment by increasing heavy metal loads in adjacent soils and streams that can bioaccumulate in animal tissues (Getz et al. 1977). Roads may encourage colonization by exotic or “edge” animal species that depredate, compete with, or parasitize forest fauna (Bennett 1991). Road access to once-remote areas facilitates new resource extraction, development, and hunting pressures, all of which may negatively impact wildlife (Mech et al. 1988, Trombulak and Frissell 2000). Finally, habitat fragmentation by roads decreases landscape connectivity for wildlife, making it difficult—and in some cases impossible—to move between formerly contiguous patches of habitat (Forman et al. 2003).

Prior research indicates the American black bear (*Ursus americanus*) is vulnerable to several of the ecological effects of roads, including road mortality (Gilbert and Wooding 1996), road-mediated changes in behavior (Brody and Pelton 1989), anthropogenic pressures associated with roads (Reynolds-Hogland and Mitchell 2007), and habitat fragmentation (Pelton 1982, Dixon et al. 2007). In combination, these impacts may produce what has been termed the *barrier effect*, or a condition in which animal movements are partially or entirely blocked by the road corridor (Forman et al. 2003). Although the black bear has been the subject of several road ecology projects

(Table 1.1), I am unaware of any study that has comprehensively examined the influence of the barrier effect upon a black bear population, in terms of both its causal mechanisms and consequences.

Bears and the Barrier Effect

Movement is a fundamental behavior of animals enabling foraging and reproduction, social interaction (Bennett 1991), repopulation of areas that have suffered local population declines and extinctions (Forman et al. 2003), and healthy gene flow among individuals and populations (Forman et al. 2003). When movement is restricted, these processes may be interrupted, limited, or prevented altogether (Bennett 1991). Prior work has demonstrated that roads serve as such a restricting agent (Mader 1984, Reh and Seitz 1990, Fahrig et al. 1995).

The barrier effect of roads yields several major consequences, essentially converse scenarios to the benefits of free movement discussed above. First, the barrier effect may restrict the normal movements of an animal within its home range, limiting its access to food, mates, and shelter (Bennett 1991). Second, the barrier effect may limit an animal's home range to an area bordered by impassable roads (Brody and Pelton 1989), or may increase competition for resources by forcing home range overlap (Maehr et al. 2003). Third, the effect may impede natural dispersal movements (Paquet and Callaghan 1996), and block range expansion and recolonization (Forman and Alexander 1998). Finally, when a road acts as a complete barrier to movement, it may subdivide populations into smaller, less-stable demographic units (Merriam et al. 1989), and may ultimately produce genetic isolation and the subsequent deleterious effects of inbreeding (Reh and Seitz 1990). Collectively, these effects can comprise a trending gradient of severity, from “early warning” consequences such as restricted within-home-range movements, to “terminal” consequences such as genetic isolation.

Impacts of roads on animals begin during initial road construction with the introduction of physical, chemical, and biotic changes to the environment. Habitats in the right-of-way are altered, formerly contiguous blocks of habitat are converted to disjunct patches, and local anthropogenic pressures such as noise and development are created. In response to these changes, an animal may modify its behavior by avoiding the road surface (Merriam et al. 1989) or cleared roadside (Oxley et al. 1974), traffic noise or emissions in the larger road-effect zone (Reijnen et al. 1995), or individual vehicles on the road (Jaeger et al. 2005). In these scenarios, movement across the road is blocked by *road avoidance*. Alternately, animals using resources along the roadway (Gibeau and Heuer 1996) or attempting to cross roads to access resources or breeding opportunities on the other side (Fahrig et al. 1995) may be killed by vehicles, in which case the barrier mechanism is *road mortality*. In short, although other factors lay the foundation for the barrier effect, road avoidance and road mortality may be viewed as the immediate causal mechanisms.

Previous work has revealed the black bear to be subject to both road avoidance and road mortality. Specific dynamics of these barrier mechanisms vary across populations, and are likely related to local cost-benefit ratios of habitat use near, and movement across, roads (Chruszcz et al. 2003, Reynolds-Hogland and Mitchell 2007). Black bears in some populations show reduced use of a buffer area around roads (Orlando 2003, Reynolds-Hogland and Mitchell 2007) and reduced road crossing levels (Brody and Pelton 1989). Black bears in other populations appear to be drawn to features of the road such as carrion (Gibeau and Heuer 1996), early-successional vegetation (Hellgren et al. 1991), and anthropogenic food sources (Beckmann and Lackey 2008), which increases their risk of road mortality (Gibeau and Heuer 1996, Beckmann and Lackey 2008). Black bears in still other populations do not exhibit road attraction, but are road-killed while moving between habitat patches (Gilbert and Wooding 1996) or while attempting dispersal (Larkin et al. 2004). To provide sufficient background information for the current study, additional discussion of black bear road avoidance and road mortality is necessary.

Road Avoidance. Several studies have documented road avoidance behavior in black bears, manifested as avoidance of the road-effect zone (Orlando 2003, Reynolds-Hogland and Mitchell 2007), avoidance of individual vehicles on the road (Jaeger et al. 2005), and/or reduced crossing of the road (Brody and Pelton 1989). The form that black bear road avoidance takes, and the types of roads it applies to, appears to be linked to the specific threats that roads represent for the population in question. For example, bears in Harmon Den Bear Sanctuary, North Carolina, were noted to be vulnerable to road mortality on nearby Interstate 40 (Brody and Pelton 1989). Accordingly, these bears crossed higher-traffic roads with lower relative frequency, and almost never crossed Interstate 40. Further, bears adjusted their home range boundaries to avoid crossing the highway (Brody and Pelton 1989). Similarly, Florida black bears (*U. a. floridanus*) in west-central Florida’s Greater Chassahowitzka Ecosystem (GCE) were killed frequently on U.S. 19 and state highways (Gilbert and Wooding 1996), and avoided an elevated noise zone extending 500 m from highways (Orlando 2003). In contrast, bears in Pisgah Bear Sanctuary, North Carolina, have been described as being more vulnerable to hunting and poaching than road mortality. Bears in this population maintained a greater buffer to lightly-used gravel roads than to paved roads, likely because gravel roads were associated with hunting and poaching activity (Reynolds-Hogland and Mitchell 2007).

A slightly different situation exists along the Trans-Canada Highway (TCH) in Banff National Park, where black bears have been observed waiting at the side of the road for a break in traffic before crossing (R. Serrouya, pers. comm.). This phenomenon, termed *car avoidance* by Jaeger et al. (2005), seemingly disregards risks associated with detection by humans, such as hunting and poaching. It might be expected to occur in areas where detection by humans does not pose a threat. Indeed, bears are protected from hunting and harassment by humans inside Banff National Park (Canada Department of Justice 2007). Car avoidance might also be expected to occur in areas where bears benefit from using roadside habitats. In Banff, black bears have been shown to be rewarded by early-successional vegetation on the verges of the TCH, carrion in the roadway, and grain spills on nearby railroad tracks (Gibeau and Heuer 1996).

In addition to avoiding the road-effect zone, avoiding individual vehicles, or refraining from crossing roads, bears exhibit a form of road avoidance by approaching and/or crossing roads only in certain areas or at certain times. In this scenario, spatial and temporal features may adjust the balance of road-related costs and benefits along the right-of-way, such that the road's permeability to bears fluctuates. Grizzly bears (*Ursus arctos horribilis*) preferentially crossed highways in areas of dense vegetative cover, where *perceived* risk of road mortality was lower, and during low-traffic hours, when *actual* road-related risks were reduced (Chruszcz et al. 2003, Waller and Servheen 2005). Grizzly bears also moved into areas of higher habitat quality when crossing busy highways, evidently weighing resource-related benefits against road-related risks (Chruszcz et al. 2003).

Road Mortality. Although the benefits of using or crossing roadways may be substantial for some populations, road mortality is a constant threat, and at the local level can be devastating (Forman and Alexander 1998). For example, Gilbert and Heuer (1996) found that 9-11% of the black bear population in Banff National Park was removed annually by transportation-caused mortality on the TCH and adjacent railway. The severity of these road-kill rates were explained by high traffic levels (14,000 vehicles/day) and speed (110 km/hour), along with black bear attraction to roadside food sources (Gibeau and Heuer 1996).

Demographic and genetic consequences may result from roadkill rates far lower than those found on the TCH. For example, in the period 1976-1995, 20 black bear road-kills in Florida's GCE were documented (Gilbert and Wooding 1996). Based on a population size of 20 bears (Maehr et al. 2003), the average annual road-kill rate during this period was only 5%. However, all known attempts by GCE bears to disperse to other populations resulted in road mortality (Gilbert and Wooding 1996, Larkin et al. 2004), indicating a complete barrier effect. Not coincidentally, GCE bears have the lowest level of genetic variability reported for any black bear population (Dixon et al. 2007).

Mitigation techniques such as wildlife overpasses and underpasses, signage, and designated wildlife "crosswalks" may decrease risk of wildlife-vehicle collisions and increase habitat connectivity (Forman et al. 2003). Mitigation is most likely to succeed when it is based on an understanding of the mechanisms underlying road mortality, including whether road-kill events can best be explained by factors influencing wildlife space use and movement, or by factors related to roads and motorists (Gunson and Clevenger 2005). Factors that have been linked to roadkill probability in other studies include habitat type, distance to hiding cover, distance to urban areas, road curvature, road width, and traffic volume (Bashore 1985, Romin and Bissonette 1996, and Clevenger et al. 2002).

Consequences. Because black bear populations exhibit causal mechanisms of the barrier effect to different degrees and are differentially exposed to road-related and ecological challenges, it is reasonable to assume that the barrier effect will not impact all black bear populations equally. In general, one might expect that populations for which patterns of road avoidance and road mortality are more pronounced, and that are subject to a busier network of roads, will display more of the consequences of the barrier effect. Anecdotally, this appears to be true. Florida's GCE bears avoid habitats within 500 m of highways (Orlando 2003) and are road-killed whenever dispersal out of the ecosystem is attempted (Gilbert and Wooding 1996, Larkin et al. 2004). Significantly influenced by both road avoidance and road mortality, GCE bears display the majority of the barrier effect consequences previously discussed, including restricted within-home-range movements (Orlando 2003), constrained and overlapping home ranges (Maehr et al. 2003), blocked dispersal (Larkin et al. 2004), and genetic isolation (Dixon et al. 2007).

Conversely, black bears from a small population in southeastern Kentucky are often observed using roadside anthropogenic food sources (Unger 2007), and are known to have made several successful crossings of an interstate highway (personal observation). Given that road avoidance and road mortality appear to be less influential in southeastern Kentucky than in the GCE, one might expect that the Kentucky black bear would display fewer consequences of the barrier effect. The history of the Kentucky black bear population directly contradicts one of the consequences of the barrier effect; the species has recolonized the region after a long period of absence (Unger 2007). Further, the Kentucky black bear population displays high genetic diversity, with no evidence of non-random mating (Frary 2008). However, while this new population appears to be contiguous with those of neighboring states, its core distribution in Kentucky is constrained to three parallel mountains near the southeastern border (Frary 2008), indicating that ecological or anthropogenic factors, including the barrier effect of roads, may be preventing further recolonization. Study of road avoidance and road mortality patterns for this population are lacking.

Black Bear Recolonization

Once abundant throughout North America, the American black bear currently occurs in relatively isolated populations throughout portions of its historic range (Pelton 1982). For example, in the southeastern U.S., 80% of the black bear's former range has been lost to human development (Pelton and van Manen 1997), with populations largely confined to the forests of the Appalachians, the Ozarks, and the coastal plain (Maehr 1984). There is evidence, however, that the tide is turning. Black bear populations are increasing and distributions expanding across much of the species' geographic range (Pelton and van Manen 1994). The black bear has naturally returned to several U.S. states from which it was once extirpated, including Texas (Onorato and Hellgren 2001), Oklahoma (Bales et al. 2005), and Kentucky, the southeastern portion of which was recolonized by bears from Virginia, West Virginia, and Tennessee (Unger 2007).

Black bears face several major challenges during recolonization that have kept this movement phenomenon a rare occurrence. First, natural obstacles such as desert (Onorato and Hellgren 2001) or open water (White et al. 2000) may block passage by would-be recolonizers. Second, ecological constraints may prevent or delay recolonization; only 7% of female black bears disperse (Rogers 1987a), and few records exist of female dispersal in excess of 15 km (Maehr 1997, Hellgren 2005). Third, anthropogenic pressures may keep the black bear out of its historic range. Like many large carnivores, the black bear is often perceived as a threat to human safety, livestock, pets, and game populations (Noss 2001). These fears inspired the predator control programs and unchecked harvests that contributed to the black bear's demise in many regions (Onorato and Hellgren 2001), and may continue to undermine recolonization via political opposition and poaching. In some regions of the U.S., poaching is further motivated by the illegal trade of bear parts (Clark and Pelton 1999).

In addition to active persecution by humans, would-be recolonizers face an onslaught of roads and other human developments that may not have been present at the time of extirpation. Movement through anthropogenic matrices may occur infrequently, as in Idaho, where black bears migrated across a broad agricultural valley at a rate of only 3 individuals per generation (Schwartz et al. 2006), and in Virginia, where 12 of 15 male black bears dispersed along the ridgelines of the Appalachians, rather than across developed areas (Lee and Vaughan 2003). If the anthropogenic matrix surrounding a bear population is hostile enough, dispersal outside of existing population boundaries may never occur. This was found to be the case in Florida's GCE, where roads created a complete barrier to movement (Maehr et al. 2003).

Roads and other anthropogenic features need not completely block bear movement in order to hamper recolonization, however. It is enough for a road to act as a selective filter, preferentially allowing bears of only one gender to cross. For example, busy highways in Slovenia were more permeable to male than to female brown bears (*Ursus arctos*) (Kaczensky et al. 2003). Similar results were obtained for grizzly bears in northwestern Montana (Waller and Servheen 2005). Recolonization cannot occur via male emigration alone, because in the absence of breeding a population cannot sustain itself (White et al. 2000). To obtain an accurate picture of a population's recolonization potential, it is important to identify across-gender differences in barrier effect mechanisms and consequences.

The Kentucky Black Bear

Once plentiful in Kentucky, the black bear was extirpated from the Commonwealth by the late 1800s as a result of overhunting and large-scale habitat destruction (Funkhouser 1925, Barbour and Davis 1974). Implementation of wildlife hunting regulations, establishment of national parks and forests, and abandonment of farms that returned to woodland established conditions have likely facilitated black bear recolonization of the Commonwealth. Although unconfirmed sightings of the black bear were reported as early as the 1920s (Funkhouser 1925), the first sighting documented by the Kentucky Department of Fish and Wildlife Resources (KDFWR) did not take place until the early 1980s (Maehr 1984). Only in the past ten years has a glimpse of the black bear become a regular occurrence in southeastern Kentucky (KDFWR, unpublished data).

A recent investigation into the size and distribution of the Kentucky black bear population yielded a population estimate of about 100 individuals found almost exclusively on Pine Mountain, Black Mountain, and Cumberland Mountain (collectively the Cumberland Mountains) at the southeastern margin of the state (Frary 2008). Although anecdotal evidence suggests that breeding is also taking place in the Big South Fork National River and Recreation Area (BSFNR) near the state's southern border, no female dispersal between BSFNR and the Cumberland Mountains has been recorded (KDFWR, unpublished data). Moreover, the BSFNR population was established as a result of reintroduction by the National Park Service, rather than through natural recolonization (Eastridge and Clark 2001). Thus, my study deals only with the Cumberland Mountains population.

Black bears of the Cumberland Mountains occupy a landscape cross-hatched with roads of various sizes, vehicle speeds, and traffic volumes (Unger 2007). As is the case in other regions, road crossing by black bears in the Cumberland Mountains yields important ecological benefits such as access to high-quality habitat patches or potential mates (Gilbert and Wooding 1996, Chruszcz et al. 2002) and dispersal to areas of lower competition for resources (Rogers 1987b). Prior radio-telemetry studies of the Kentucky black bear indicate some crossing of major roads, particularly during long-distance movements (Unger 2007). At a population scale, one might predict that the benefits of road crossing are greater for bears dispersing or searching for mates, and in areas linking good habitat. Net reward can be increased by crossing roads in areas or at times of day that minimize road-related risks (Chruszcz et al. 2003).

Field observations of the Kentucky black bear indicate that animals using habitats near roads are often rewarded with anthropogenic food. Unaccustomed to living with black bears, the people of eastern Kentucky are only beginning to adopt the bear stewardship practices recommended by KDFWR. Unsecured garbage and animal feed in residential areas, dumpsters in town, and picnic waste and leftovers at state parks represent tempting "accidental" food sources for bears. In addition, bears are often intentionally fed (S. Dobey, KDFWR, pers. comm.). Although bears reliant on anthropogenic food are depicted as "bad bears," garbage as a food source makes sense from an energetics standpoint, because it is plentiful year-round, predictably located, highly clumped, and frequently replenished (Beckmann and Berger 2003). Moreover, reliance on anthropogenic food has been linked to high fecundity rates in other populations (Beckmann and Lackey 2008), and in Kentucky, may be partially responsible for an above-average litter size and low first age of reproduction (Unger 2007). Because anthropogenic food tends to be found in close association with roads, it can be considered a major benefit of using roaded areas. Like road-related costs, this benefit likely fluctuates in space and time. A greater reward should be offered in developed areas, on garbage pick-up day in residential areas, and on weekends in state parks and other recreational areas. A greater *net* reward (benefit minus cost) is available to those bears accessing anthropogenic foods at times when risk of human conflict is lower, as during nocturnal hours (Beckmann and Berger 2003).

For the Kentucky black bear, the most obvious road-related threat is road mortality. The first documented roadkill of a black bear in Kentucky was in 1993, and roadkill events have increased in frequency since that time. Risk of being poached represents a second major road-related threat, as illegal kills account for a significant fraction of bear mortality in Kentucky (KDFWR, unpublished data). The black bear was listed as threatened under the KDFWR State Comprehensive Wildlife Strategy for the duration of this study, so hunting did not factor into an inventory of costs along roadways in the Cumberland Mountains. In general, risk of road mortality increases with traffic volume (Jaeger et al. 2005) and risk of poaching or harassment with development, although the latter may also be high on lightly-used recreational or industry roads (McLellan and Shackleton 1988, Reynolds-Hogland and Mitchell 2007). Both risks should decrease at night, as human activity wanes (Gibeau et al. 2002).

Research Objectives

1) Identify and measure patterns of road avoidance in the Kentucky black bear
    a. Characterize space use with respect to roads at home range and landscape scales
    b. Characterize patterns of road crossing, including spatial and temporal attributes of crossing events
2) Characterize patterns of road mortality in the Kentucky black bear, including spatial attributes of roadkill events
3) Characterize the influence of the barrier effect on the Kentucky black bear
    a. Assess cumulative impacts of road avoidance and road mortality
    b. Discuss the current and potential role of the barrier effect in limiting continued black bear recolonization of the Commonwealth

Hypotheses and Predictions

Road Avoidance. My first hypothesis is that the Kentucky black bear displays some form of road avoidance. Predictions in support of the *Road Avoidance: Present* hypothesis include: 1) bears establish home ranges with lower road densities than expected, relative to what is available in the study area, 2) bears use habitats farther from roads than expected, relative to what is available within their home ranges, and 3) road crossings are distributed non-randomly along the road with respect to certain habitat, landscape, and anthropogenic features. Predictions 2 and 3 will be validated even if determined to be true for only one diel period or traffic class. In fact, because road avoidance in black bears is believed to be linked to road-related risks that vary across space and time (Orlando 2003, Reynolds-Hogland and Mitchell 2007), rather than to unchanging aspects of the road itself, I anticipate observing spatial and temporal differences in road avoidance patterns. The *Road Avoidance: Present* hypothesis will be upheld if one or more of the above predictions are validated for one or both of the sexes, or in one or both regions of the study area.

My second hypothesis is that road avoidance patterns in the Kentucky black bear reflect road-related costs and benefits. Specifically, I hypothesize that road avoidance patterns are a function of the twin risks of road mortality and harassment by humans, versus roadside anthropogenic food sources and ecological benefits of connectivity. To uphold the *Road Avoidance: Cost/Benefit* hypothesis, at least one prediction from each of the following sets needs to be met for one or both of the sexes, or in one or both regions of the study area: 1) crossing of well-traveled roads is avoided, and crossing of lightly-traveled roads preferred, relative to their abundance in bear home ranges, 2) crossing rates of well-traveled roads are higher at night, when traffic levels are low, than during daytime and crepuscular periods, 3) average distance to well-traveled roads is higher during daytime and crepuscular periods, when traffic levels are high, than at night, or 4) crossing rates of and habitat use near lightly-traveled roads show lower diel variation than crossing rates of and habitat use near well-traveled roads; and 1) average distance to human use features is higher during daytime and crepuscular periods, when human activity levels are high, than at night, or 2) daytime and crepuscular road crossing occurs in locations farther from human use features than nighttime crossing.

Road Mortality. I hypothesize that road-kills are not distributed randomly across the Kentucky road network, but occur where habitat, landscape, or anthropogenic features favor bear travel and/or contribute to road mortality risk. I further hypothesize that unsuccessful road crossing attempts (roadkills) possess different site attributes than successful crossing attributes. While habitat and landscape parameters favoring bear travel should be common to roadkill and road crossing sites, certain anthropogenic features should be more likely to lead to collisions and should, thus, be more significantly associated with roadkill locations. In particular, I anticipate no significant difference for topographic parameters, distance to human use features, or large-scale land cover composition between roadkill and road crossing locations, because these factors should be more responsible for shaping bear space use and movement than influencing mortality risk. I anticipate differences in traffic volume, road sinuosity, distance to forest cover, and small-scale land cover composition between road crossing and roadkill sites. Higher traffic volumes and straighter (therefore more fast-moving) sections of road should decrease a bear's chance of crossing a road successfully. Following that logic, high-traffic, fast-moving roads generally occupy larger footprints than their more lightly-traveled counterparts, which should produce a preponderance of the 'developed' land cover category at small scales, and larger distances to forest cover from the road center. The *Road Mortality: Mechanisms* hypothesis will be upheld if either of the following predictions is validated: 1) road-kills are distributed non-randomly along the road with respect to certain habitat, landscape, and road features, or 2) factors influencing general space use and movement do not differ significantly between roadkill and road crossing locations; factors influencing road mortality risk do differ significantly between roadkill and road crossing locations.

Further, I hypothesize that road mortality will not affect all demographic groups equally, but will be most prevalent among bears likely to travel long distances. Predictions in support of the *Road Mortality: Traveler* hypothesis include: 1) black bear males have higher road mortality than females because males are more likely to disperse (Rogers 1987a), occupy larger home ranges (Garshelis and Pelton 1981), and travel longer daily distances (Garshelis et al. 1983) than females; and 2) subadult black bears have higher road mortality than adults, since dispersal in black bears usually occurs before age three (Lee and Vaughan 2003).

Barrier Effect. I hypothesize that the Kentucky black bear is, indeed, subject to the barrier effect of roads. Predictions in support of the *Barrier Effect: Present* hypothesis consist of two "early warning" consequences of the barrier effect, namely: 1) black bears have restricted within-home range space use and movements, evidenced by higher-than-expected distance to roads and/or reduced permeability of roads across spatial, temporal, or demographic bounds and 2) black bears do not make full use of the landscape available to them, evidenced by lower-than-expected home range road densities. Although validation of either of the above predictions will be considered sufficient to uphold the *Barrier Effect: Present* hypothesis, additional validations will strengthen a "positive" diagnosis, and will support the idea that continued black bear recolonization of the Commonwealth might be hampered by the barrier effect of roads.

Table 1.1. Summary of road ecology studies of the American black bear.

Study	Population	Status[a]	Primary mortality[b]	*N*	Sampling intensity	Mechanism studied[c]	Road response[d]
Orlando 2003	GCE, FL	Pr	RM	4 F, 5 M	1 time/wk	RA	Bears avoided habitats < 500 m from 1° hwys, < 300 m from 2° rds
McCown et al. 2004	Ocala National Forest, FL	Pr	RM	49 F, 46 M	1-3 times/wk	RC, RM	M more likely to cross roads than F; RM positively correlated with RS
Hellgren et al. 1991	Great Dismal Swamp, VA	LP		24 F	1-7 times/wk	RA	Bears selected habitats < 800 m from rds, except fall
Beringer et al. 1990	Harmon Den, NC	LP	H	16 F, 8 M	1 time/6-20 hrs	RC	RC negatively correlated with TV, positively correlated with daylight
Brody and Pelton 1989	Harmon Den, NC	LP	H	17	2-5 times/wk	RC	RC negatively correlated with TV, interstate hwy bordered home ranges

Table 1.1 (continued).

Reynolds-Hogland and Mitchell 2007	Pisgah Bear Sanctuary, NC	LP	P	66 F, 52 M	$\leq$1 time/2 hrs	RA	Bears avoided unpaved rds > paved; Both sexes avoided habitats < 800 m from rds (M summer only); higher use of habitats near rds in fall
Carr and Pelton 1984	Great Smoky Mtns National Park, TN	Pr		7 F	1 time/hr - 1 time/day	RA, RC	Bears freely crossed roads < 100 ADT; use of roaded areas varied with seasonal foraging, not visitor use; no effect of rep. phase
Fescke et al. 2002	Garrett County, MD	Pr		5 F	2-3 times/wk	RA	Bears avoided 1° hwys but not 2° or unimproved rds; F with cubs used lower RD areas
Clark et al. 1993	Ozark Mtns, AR	H		14 F	$\leq$1 time/hr	RA	F avoided habitats < 240 m from rds

Table 1.1 (continued).

Kasworm and Manley 1989	Cabinet Mtns, MT	H		17 F, 9 M		RA	Bears avoided habitats < 275 m from rds spring and < 915 m from rds fall; no effect of rep. phase
Young and Beecham 1986	Priest Lake, ID	H		5 F, 4 M	1 time/2 days	RA	F avoided rds; M used rds in proportion to availability
Percy 2003	Banff National Park, AB	Pr	RK	7 F, 11 M	1 time/2 hrs	RC	RC negatively correlated with TV and TR, positively correlated with daylight and distance to HU

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[a] LP=locally protected, with no harvest, although bears move between protected and unprotected areas; Pr=protected, with no harvest, and no known movement into unprotected areas; H=harvested

[b] H=hunting, P=poaching, RM=road mortality

[c] RA=road avoidance, RC=road crossing, RM=road mortality

[d] F=female, M=male, ADT=average daily traffic, HU=human use areas, RC=road crossing, RD=road density, RM=road mortality, RS=road sinuosity, TR=terrain ruggedness, TV=traffic volume

CHAPTER 2

STUDY AREA

This study was conducted in and around the Kentucky black bear core area of distribution, where all trapping took place and the bulk of GPS location data were collected, and over a larger area spanning the eastern one-third of the state, where roadkill data were collected (Figure 2.1). The core and non-core portions of the study area differed considerably in terms of topography and land cover. Additionally, slight differences existed between Pine Mountain and Cumberland Mountain, the two primary trapping regions in the core portion of the study area.

The core portion of the study area centered on the Cumberland Mountains, a set of three parallel mountains running northeast-to-southwest along the border between Kentucky and Virginia. Average elevation in this region was 450 m, with isolated high points of 975 m on Pine Mountain, 1262 m on Black Mountain, and 1018 m on Cumberland Mountain (Homer et al. 2004). The northernmost of the Cumberland Mountains was Pine Mountain, a 193-km ridge extending from Elkhorn City, Kentucky to Jellico, Tennessee, marked by steep northwestern and gradual southeastern slopes. Pine Mountain was intersected by 6 roads in the core portion of the study area: US-23 near Jenkins, US-119 near Whitesburg, KY-160 near Cumberland, KY-2010 near Putney, US-421 near Harlan, and US-25E in Pineville. Additionally, the lightly-traveled, intermittently-paved KY-1679 (Little Shepherd Trail) ran the ridgeline of Pine Mountain for approximately 50 km from US-119 to US-421. At lower slopes, Pine Mountain was traversed by numerous residential roads. The middle of the three Cumberland Mountains was Black Mountain, which, despite extensive surface mining operations, is still Kentucky's highest point (Homer et al. 2004). Black Mountain was spanned primarily by unpaved roads maintained by resource extraction companies. The southernmost of the Cumberland Mountains was Cumberland Mountain, which essentially mirrored the topography of Pine Mountain, with gradual northwestern and steep southeastern slopes. Cumberland Mountain was intersected by three major roads in the core portion of the study area, US-23 at Big Stone Gap, US-421 at Pennington Gap, and US-25E at the Cumberland Gap. US-25E crossed Cumberland Mountain through the Cumberland Gap Tunnel, which was constructed in 1996 and the original roadbed removed as part of the Cumberland Gap Restoration Project (Unger 2007). Cumberland Mountain was also negotiated by unpaved recreational roads at higher elevations and residential roads at lower elevations.

Road density in the core portion of the study area averaged 1.24 km/km^2. Land cover consisted of 79.9% forest, 12.4% open, 3.8% agricultural, 3.6% developed, and 0.3% open water and wetlands. These attributes varied slightly between the two regions in which trapping took place, Pine Mountain and Cumberland Mountain, with higher road densities on Pine Mountain and a greater proportion of agricultural land on the lower slopes of Cumberland Mountain (Table 2.1, Figure 2.2).

The non-core portion of the study area spanned 29 counties, and was bounded by Boyd County to the north, Pulaski County to the west, Whitley County to the south, the foothills of Pine Mountain to the southeast, and Pike County to the east. Most of the non-core area occurred within the Cumberland Plateau, a region characterized by forested hills and deep, narrow valleys (Thornbury 1965). Elevations in this area were generally between 300 and 500 m (Homer et al. 2004). The region contained an extensive road network including I-75, I-64, US-23, US-421, US-460, KY-11, KY-15, KY-80, and a myriad of lower-traffic roads (Figure 2.1). Additionally, the proposed I-66 was slated to traverse the non-core portion of the study area through Pulaski, Laurel, Clay, Leslie, Perry, Knott, and Pike Counties (C. Blair, Kentucky Transportation Cabinet, pers. comm.). Road density in the non-core region of the study area was 1.24 km/km^2. Land cover in this region consisted of 68.3% forest, 14.2% agricultural, 9.8% open, 6.9% developed, and 0.83% open water and wetlands.

Forest in both the core and non-core portions of the study area was primarily deciduous, with stands of evergreen trees in rich coves and on sandy ridgetops. Dominant tree species at lower elevations included yellow poplar (*Liriodendron tulipifera*), sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*), American basswood (*Tilia americana*), red oak (*Quercus rubra*), white oak (*Quercus alba*), red maple (*Acer rubrum*), eastern hemlock (*Tsuga canadensis*), black walnut (*Juglans nigra*), black cherry (*Prunus serotina*), shagbark hickory (*Carya ovata*), black gum (*Nyssa sylvatica*), and white ash (*Fraxinus americana*). Dominant tree species at higher elevations included chestnut oak (*Quercus prinus*), scarlet oak (*Quercus coccinea*), and black oak (*Quercus velutina*), with associated species such as yellow poplar, sugar maple, American beech, pitch pine (*Pinus rigida*) and Virginia pine (*Pinus virginiana*) (Wharton and Barbour 1973). Open areas in both the core and non-core portions of the study area included reclaimed surface mines, generally planted in exotic grasses and forbs including tall fescue (*Festuca arundinacea*) and bush clover (*Lespedeza spp.*) (Frary 2008). Average annual temperature across both portions of the study area was 13° C, and average annual precipitation was 120 cm (National Climatic Data Center 2009).

Table 2.1. Road density and land cover composition of Pine and Cumberland Mountains, Kentucky in the core portion of the black bear study area, 2005-08.

	Rd. density	Land cover composition (%)				
Region[a]	(km/km^2)	Forest	Open	Developed	Agricultural	Water/wetland
PM	1.24	88.9	6.7	3.3	0.7	0.4
CM	0.88	87.1	4.2	2.6	5.6	0.6

[a] PM = Pine Mountain, CM = Cumberland Mountain

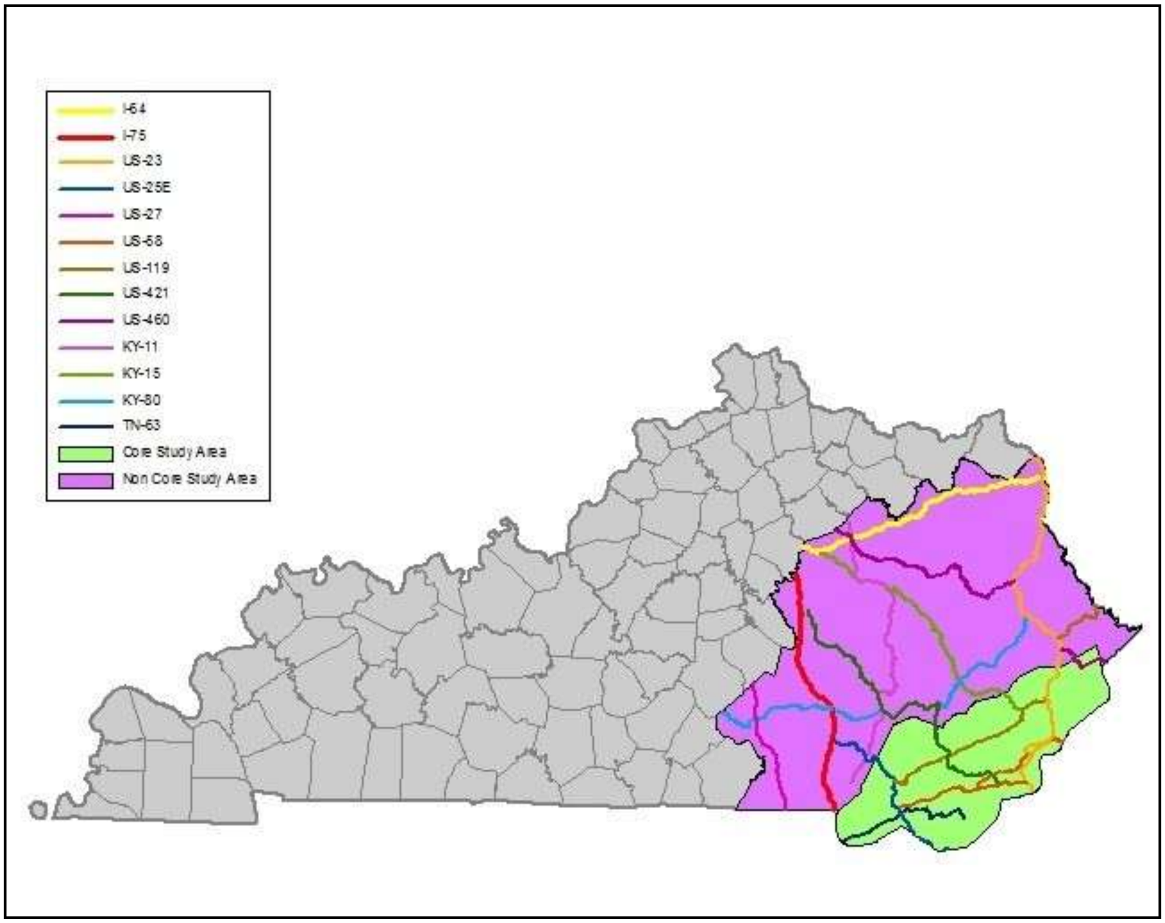


Figure 2.1. Major roads in the core and non-core portions of the black bear study area, eastern Kentucky, 2005-08.

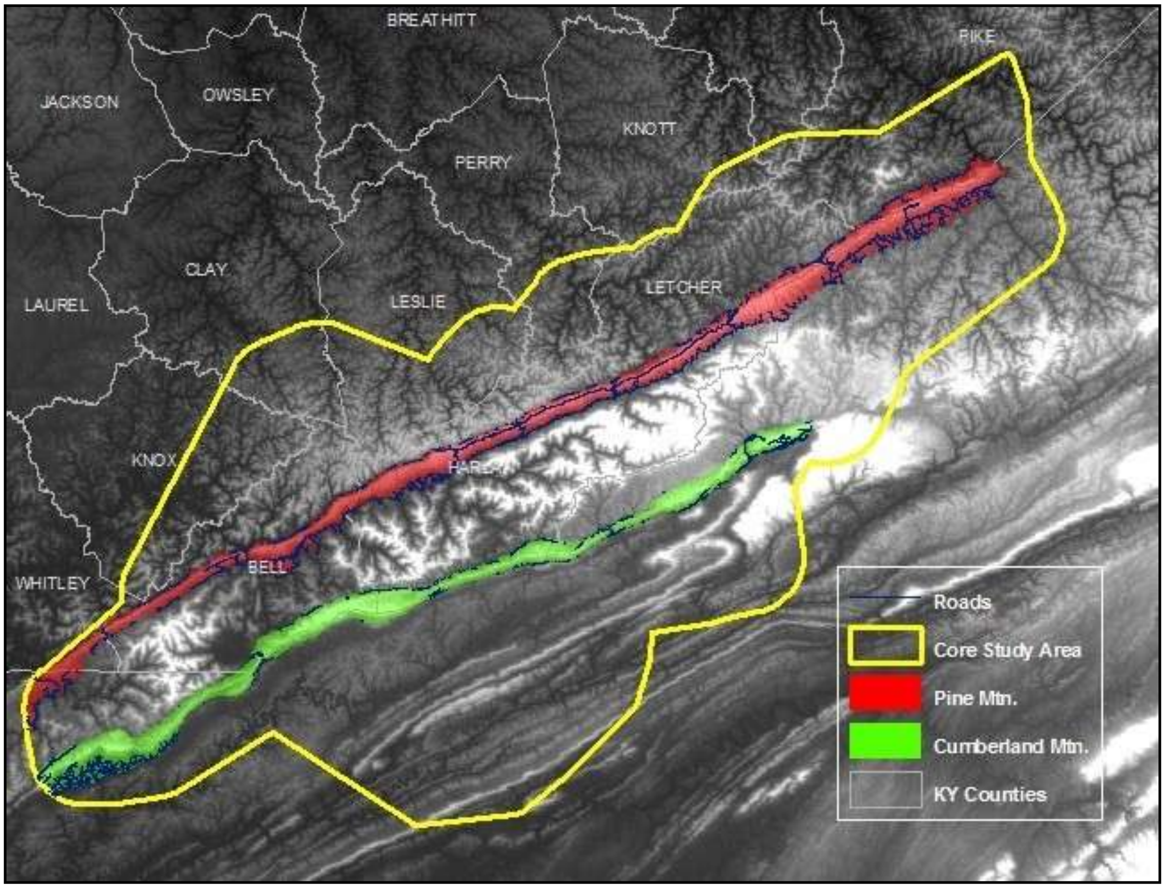


Figure 2.2. Topographic configuration and road networks of Pine and Cumberland Mountains, Kentucky in the core portion of the black bear study area, 2005-08.

CHAPTER 3

METHODS

Capture and Handling

Bears were captured between May 2005-June 2008 using a variety of methods that included modified Aldrich spring-activated foot snares (Johnson and Pelton 1980), passive PVC snares (Reagan et al. 2002), culvert traps, and free-darting. Capture locations on Pine Mountain included Kentenia State Forest, Kingdom Come State Park, Hensley-Pine Mountain Wildlife Management Area, and the private property of Jim Webb. Capture locations on Cumberland Mountain included Cumberland Gap National Historical Park and Shilallah Creek Wildlife Management Area. Additionally, several bears were captured as nuisance animals in residential areas on or near Pine Mountain. Regardless of whether captures occurred as the result of research trapping or nuisance management, University of Kentucky personnel were present and conducted procedures in accordance with the University of Kentucky Institutional Animal Care and Use Committee Protocol # 626A2003.

Animals were immobilized using Telazol® (Fort Dodge Animal Health, Fort Dodge, IA) administered at 4.4 mg/kg estimated body weight (Kreeger 1996) via pole syringe or cartridge-fired or air-activated projector (Pneu-Dart, Inc., Williamsport, PA). Following immobilization, artificial tears (Vedco, St. Joseph, MO) were applied to the eyes to prevent drying, and initial temperature, respiration, and pulse were measured. Animals with body temperatures over 100° F (37.8° C) were cooled to normal temperatures using ice packs or external applications of water or rubbing alcohol. Any trap-related injuries were treated and documented. Each animal was then marked with uniquely-numbered eartags, lip and inguinal tattoos, and a passive integrated transponder (PIT) tag (Biomark, Inc., Boise, ID) injected between the shoulder blades. The apparent redundancy in marking methodologies was warranted by observations that animals recaptured many years after initial marking may have illegible tattoos and missing eartags (B. Augustine, University of Kentucky, pers. comm.).

A veterinary tooth elevator was used to extract a first upper premolar tooth from all bears field-aged at one year or older (Willey 1974). Extracted teeth were aged using cementum annuli counts (Matson's Laboratory, LLC, Milltown, MT). Guard hairs were collected from each bear for genetic analysis. The following standard body measurements were taken using flexible measuring tape: total length, chest girth, shoulder height, forearm circumference, head length and width, zygomatic circumference, neck circumference, ear length, and foot pad length and width. Weight was either estimated or, if sufficient personnel were present, measured using a drop scale and nylon net.

Bears field-aged at ≥ 2 years were fitted with one of the following models of Global Positioning System (GPS) radiocollars: Lotek 3300, Lotek 4400M, or Lotek 8000MGU (Lotek Wireless, Inc, Newmarket, Ontario, Canada). All models were equipped with GPS receivers and Very High Frequency (VHF) beacons. The GPS module collected position information, as well as activity and temperature data. The VHF beacon allowed animals to be located using aerial or ground telemetry, and alerted telemetry technicians to potential mortalities or collar drop-offs via a 4-hour inactivity mortality switch. Collar models differed primarily in how data were retrieved. The

Lotek 3300 was a “store-on-board” model, meaning the collar had to be physically retrieved in order to upload GPS fix data. The Lotek 4400M model featured an Argos transmitter enabling remote retrieval of data via a satellite-based relay system (CLS America, Inc., Largo, MD), as well as a UHF modem enabling field retrieval of data using a UHF receiver. The Lotek 8000MGU model contained a Global System for Mobile Communication (GSM) modem enabling remote retrieval of data via mobile phone technology, as well as the UHF capabilities described above. Collars were programmed to attempt GPS fixes every 30 minutes, 1 hour, 2 hours, or 4 hours. All collars were equipped with an electronic drop-off mechanism (Lotek Wireless, Inc, Newmarket, Ontario, Canada) designed to trigger collar release after a pre-set time interval, as well as a leather spacer ensuring collar drop-off in the event of electronic drop-off failure.

Telemetry

Bears were located regularly using telemetry from fixed-wing aircraft. Aerial telemetry was a necessary supplement to GPS data collection because it prevented losing track of animals (particularly those wearing store-on-board collars), allowed researchers to quickly identify mortality events and collar drop-offs, and aided agency management activities. Moreover, flights were necessitated by a sample of bears equipped with VHF-only radiocollars that were being monitored for research not related to this project. During active seasons, bears were located once per week; however, during the typical hibernation period flights were reduced to once every 2-3 weeks to reduce project expenses.

When a mortality signal was observed, a ground telemetry mission quickly ensued to search for the carcass or dropped collar. In instances where foul play was suspected, a KDFWR conservation officer accompanied UK researchers in ground searches. Regardless of whether telemetry flights indicated potential mortality or management issues, all telemetry data were promptly disseminated to KDFWR wildlife biologists.

Data Filtering

All collar date/time data were standardized to Eastern Standard Time (GMT-0500). Bears with < 30 days of GPS location data were not considered for analyses. Collar data were converted from the WGS 84 to the NAD 83 datum to match the majority of data layers accessed from state agencies and the USGS Seamless Server. Data were then subjectively filtered to remove clustered locations associated with animal capture, collar drop-off, and mortality.

A cursory examination of the collar data indicated that some individuals had atypical, large movements that appeared to reflect GPS fix errors. Because these data points could influence movement-related analyses, I analyzed bear movement paths to identify and remove potentially large location errors. First, I converted each bear's set of locations to paths using Hawth's Analysis Tools version 3.27 in ArcGIS 9.2 (ESRI, Redlands, CA). I obtained typical movement rates by calculating the length of non-denning path segments produced by consecutive fixes < 4 hours apart, then dividing each segment's length by its time duration. An independent two-sample t-test (α=0.05) revealed that movement rates differed significantly by gender (t_{20}=-2.79, P = 0.011); hence, I removed potentially erroneous locations separately for males and females. I flagged those path segments outside the 99.9th percentile of each gender's set of movement rates, and spatially examined their bounding set of locations as follows. Given a 2-step chronological movement sequence consisting of 3 locations (A-C), point B being the potential erroneous location, if BC < AC, I retained B; if BC > AC, I considered B erroneous and discarded it.

I divided Kentucky black bear location data into 4 biological seasons: pre-breeding, breeding, fall hyperphagy, and denning. I defined pre-breeding as the period from the end of denning to 31 May; breeding as the period between 01 June through 15 August, and fall hyperphagy from 16 August through denning. I defined the denning season separately for males, females that were pregnant or caring for cubs of the year, and females caring for yearlings or actively breeding, based on previous observations that these demographic groups have different den entry and emergence dates (Oli et al. 1997) and different behavior with respect to roads (Fecske et al. 2002, Reynolds-Hogland and Mitchell 2007). No pre-reproductive female was tracked as part of this study.

I used a novel methodology to define denning dates for each group according to major changes in movement rates. My choice was based on previous observations that most adult females with cubs exhibited characteristic denning behavior with little to no movement outside of dens, while most adult males and females with yearlings displayed “pseudo-denning” behavior characterized by lack of a central den location, and shorter, more infrequent movements within the home range as compared to other seasons (Unger 2007). My goal was not to estimate dates of entrance into and emergence from den structures, but to define typical periods of depressed movement for each group.

For each bear with location data derived from ≥ 3 calendar seasons, I obtained mean hourly movement rates by week, and the standard deviation of these weekly means.

I then averaged standard deviation values within each gender, yielding 123.0 m/hr for males ($n = 7$) and 67.7 m/hr for females ($n = 10$) (Table 3.1). Next, for bears with location data derived from winter plus one other calendar season, I plotted each animal's mean hourly movement rates as a function of week of the year. Using the standard deviation prescribed by gender, I obtained a "*d*-value" for each bear, defined as one standard deviation above a bear's lowest mean hourly movement rate of the winter. The start of each bear's denning season was the week in which the bear's mean hourly movement rate dipped below that bear's *d*-value for the last time. The end of each bear's denning season was the week in which the bear's mean hourly movement rate climbed above that bear's *d*-value for the first time (Figure 3.1). I obtained estimated start and end dates by taking the midpoint of start and end weeks for each bear. Start and end dates were then averaged across bears within each group, yielding 6 December to 17 May for females with natal dens, 22 December to 3 April for females denning with yearling cubs, and 19 December to 22 April for males (Table 3.2).

I stratified bear locations by time of day to examine potential temporal patterns of road use or avoidance. I split the 24-hour clock into 3 diel periods based on a sunrise-sunset schedule averaged across 2 month periods for Harlan, Kentucky: daytime (2 hours after sunrise to 2 hours before sunset), crepuscular (2 hours before sunrise to 2 hours after sunrise, and 2 hours before sunset to 2 hours after sunset), and nighttime (2 hours after sunset to 2 hours before sunrise).

I obtained spatial and traffic count data for roads within the study area from the Kentucky Transportation Cabinet, Virginia Department of Transportation, and Tennessee Department of Transportation. I used average daily traffic (ADT) values collected from

2007-2008 (for GPS collar data) and from 1996-2008 (for roadkill data) to classify roads into 4 traffic classes: very high (≥ 12,000 vehicles/day), high (6,000-11,999 vehicles/day), moderate (600-5,999 vehicles/day), and low (< 600 vehicles/day). While there appears to be no standard for ADT classification in the literature, my very high traffic class had a minimum ADT threshold identical to that of class 1 roads used by Orlando (2003), and my low traffic class encompassed the ADTs given for class II and class III roads in Beringer et al. (1990). I subjectively classified roads for which ADT values were not available through comparison to their feeder roads and other surrounding roads that had ADT values, in order to arrive at the best assignment.

I obtained the Kentucky National Land Cover Database (NLCD) 2005 from the Kentucky Division of Geographic Information. The data consisted of a 30-m raster that divided statewide lands into 15 land cover categories. I reclassified the raster to 5 general land cover categories most biologically relevant to black bears (Table 3.3).

A visual comparison of the NLCD 2005 and 2004 National Agriculture Imagery Program (NAIP) 1-meter orthoimagery of the study area revealed that the NLCD failed to delineate small-scale features such as buildings and forest margins. Moreover, overall accuracy of the NLCD is reported at 60%. Accurate building and forest polygon layers were essential for distance analyses related to road crossing and road mortality. Hence, I used Feature Analyst 4.2 (Visual Learning Systems, Missoula, MT) in ArcGIS 9.2 to identify buildings and trees in orthoimagery, and extract them as polygon shapefiles (Figure 3.2). These features were batch extracted within an area spanning all GPS locations and within a 1-km buffer surrounding each roadkill site. I used 2004 NAIP orthoimagery for batch extraction at roadkills occurring from 2000-2008, and 1995

Kentucky Geological Survey 1-meter digital orthophoto quarter quadrangles (DOQQ) at roadkills occurring from 1993-1999. For batch extraction in the area spanning GPS locations, I used the 2004 NAIP orthoimagery only. Following extraction, I manually removed clutter (polygons that were not actually buildings or trees) and added missing features (buildings or trees omitted from the polygon shapefiles). The completed shapefiles had a detection rate of 79.6%, with the remainder representing target shapes that were not extracted, and accuracy of 87.9%, with the remainder representing non-target extraction. These methods marked an improvement over the NLCD sufficient to warrant use in this study.

I obtained 10 m (1/3 arc-second) National Elevation Dataset (NED) grids from The National Map Seamless Server (U.S. Geological Survey 2009) for an area spanning all GPS collar locations and roadkill locations. I used ArcGIS 9.2 Spatial Analyst to derive slope grids from the NED grids, and to mosaic constituent grids into single, large NED and slope grids for ease of data analysis.

Road Avoidance

Road avoidance was assessed both in terms of second-order selection, or placement of home ranges on the landscape relative to roads, and third-order selection, or within-home-range space use relative to roads (Johnson 1980). The former was addressed through road density analyses, and the latter through distance-based analyses. Results were considered significant at $\alpha=0.05$ for all analyses in this study.

Road Density. I defined the scale over which second-order selection would be investigated using a composite home range approach similar to Mace et al. (1996). I constructed 95% minimum convex polygons (MCPs) for each of my bears using Biotas

1.03 Alpha (Ecological Software Solutions, Urnäsch, Switzerland). I overlaid and merged the MCPs to create a composite home range, then buffered the composite home range by 8.3 km, the average radius of the 95% MCPs constructed in the first step. The resulting polygon spanned 145,678 km^2, and was used as my study area for road density purposes (Figure 3.3). I used MCP home ranges rather than fixed kernels to define the road density study area because I wished to include areas that were not selected by bears, per typical investigation of second-order selection (Clark et al. 1993), and felt a composite kernel would produce boundaries too conservative to portray the full landscape available to bears in this study. I chose the 95% isopleth to exclude sallies outside of typical use areas (Mace et al. 1996).

I assessed road density for those bears and female reproductive phases providing location data from at least 2 of the 3 non-denning ("active") seasons. A minimum of 10 days of location data was required per season. Using active season data only, I generated 50% fixed kernel core areas and 95% fixed kernel home ranges for eligible bears using Biotas 1.03 Alpha. The least squares cross validation method was used to derive optimal bandwidth for kernel home ranges. I compared overall road density, road density of each traffic class, and relative frequency of each traffic class within each bear's 50% and 95% kernel to that of 100 polygons equivalent in area to the actual kernel and placed randomly throughout the study area (Figure 3.4). I examined relative frequency in addition to road density because I wished to characterize road network composition of home ranges, including whether certain traffic classes were used disproportionately to their occurrence on the landscape. Relative frequency was expressed as length of a particular traffic class over length of the home range road network, and was examined only for those home ranges containing roads. I used paired t-tests to compare observed and mean expected road density values, and Wilcoxon rank-sum tests to compare observed and mean expected relative frequencies of road classes. I used independent two-sample t-tests to compare the actual road density values of the two genders, regions, and female reproductive phases, and to compare male road density values to those of each of the two female reproductive phases.

Distance Analyses. I conducted within-home-range distance analyses for the same sample of bears used in the road density analysis, comparing each bear's full set of active-season locations to 1000 random locations drawn from the bear's 95% MCP home range. I chose the MCP over the kernel because I wished to retain a more generous estimate of total home range space available to each bear. As with the road density analyses, I chose the 95% isopleth to exclude sallies outside typical use areas.

I calculated the Euclidean distance from each bear's set of used and available locations to roads and buildings using ArcGIS 9.2 Spatial Analyst. Separate calculations were made for all roads pooled and roads of each of the four traffic classes. I compared mean observed and expected distance values using paired t-tests stratified by gender, region, female reproductive phase, and diel period. I used independent two-sample t-tests to identify differences between distance values of the two genders, regions, female reproductive phases, and between males and each of the two female reproductive phases. Additionally, I used 1-way ANOVA tests to examine the relationship between distance to roads and buildings and diel period.

Road Crossing

GPS Collar Error. Most of my study animals had collar locations on or within several meters of roads. This presented a problem in the identification of road crossing events, because what appeared to be road crossings might have been GPS fixes erroneously located across the road. I assessed the error distance of my GPS collars by testing two Lotek 3300 collars at 37 sites of four different cover types: deciduous, mixed, evergreen, and open. Collars were programmed to attempt fixes hourly, and remained at each site for a minimum of 16 hours. At 20 sites, collar locations were compared with locations obtained with a Trimble GEOXM2005 Series GPS unit (Trimble Inc., Dayton, OH) differentially corrected to within 3 m accuracy. At the remaining 17 sites, each collar location was compared with the average of all collar locations per site. I calculated the 50% circular error probable (CEP) for each site, or the distance from the true location within which 50% of collar locations fell, using DNR Garmin for ArcGIS (Minnesota Department of Natural Resources 2001). I averaged 50% CEP values within each cover type, and weighted mean CEP values by the proportion of each cover type in the study area to obtain an overall mean 50% CEP. I applied this distance as a buffer to the roads layer, and removed all collar locations contained within.

Road Crossing Events. Following removal of collar locations within error distance of roads, I used Hawth's Analysis Tools version 3.27 to create a single, multi-segmented movement path for each bear. Next, I queried those segments produced by consecutive locations ≤ 4 hours apart. Finally, I intersected queried movement segments with the roads layer, yielding a set of estimated road crossing locations for each bear. Although 4-hour path segments do not detect all the nuances of bear movement, this cut point represented an improvement in accuracy over previous studies, which have used path segments of up to 24 hours in duration to identify bear road crossing locations (Chruszcz et al. 2003). Only those bears with ≥ 30 or more estimated road crossing locations were used for this analysis.

I compared road crossing frequencies of males and females as follows. First, because males had a lower average GPS collar fix rate than females, I sub-sampled location data of males with a 0.5-hr fix interval to a minimum interval of 1 hr. This resulted in average GPS collar fix rates that were not significantly different from one another ($t_{17} = 0.82$, $P = 0.4$). Next, I divided number of road crossings for each bear by number of days in which crossings could be made, defined here as days outside of the denning period in which the GPS collar was worn. Finally, I compared the daily crossing rates of males and females using independent two-sample t-tests.

Site Attributes. I drew random on-road locations for each eligible bear, constrained to that bear's 100% MCP home range and equal in size to the bear's actual road crossing sample. These were considered to be a bear's set of available road crossing locations. The full sample of used and available road crossing locations for each bear was used in the traffic class analysis. The remaining seven road crossing variables were analyzed using the smaller of either a bear's full sample of used and available road crossing locations, or a subset of 70 used and available road crossing locations randomly drawn from a bear's full sample, representing 10 units per variable.

At each used and available road crossing location, I measured the following variables: traffic class, distance to buildings, distance to forest cover, elevation, slope, terrain ruggedness, land cover composition, and road sinuosity. Distance to buildings, distance to forest cover, and elevation were point-based measurements originating from on-road locations within 100 m of used and available road crossings. Terrain ruggedness, slope, and land cover composition were measured within 100-m, 500-m, and 1000-m buffers surrounding each used and available road crossing location. Road sinuosity was measured within 100-m and 500-m buffers only. Finally, traffic class was measured at the whole-road scale, with crossing locations assigned to the class of the roads on which they lay. Road crossing site attributes were analyzed by gender and, in some instances, by female reproductive phase.

I used Chi-square goodness-of-fit and Wilcoxon rank-sum tests to compare observed and expected crossing frequencies of the four traffic classes. I assigned each used and available road crossing to the traffic class of the section of road on which it lay, tallied occurrences of the four traffic classes within each gender's set of used and available road crossings, and weighted occurrences by the relative contribution of each bear to the total pool of crossing events. The resulting tables were subjected to Chi-square goodness-of-fit testing by gender and for pooled bears. Since neither of the female reproductive phases produced the minimum 5 expected observations per category required for Chi-square, the classes could not be analyzed separately. I used Wilcoxon rank-sum tests to identify those traffic classes and diel periods accounting for a significantly larger or smaller proportion of road crossing events than expected, by gender, female reproductive phase, and for pooled bears. Road crossing tallies by diel period were weighted separately for each season to reflect the relative contribution of each diel period to the 24-hour clock in that season. Additionally, I used Kruskal-Wallis tests to examine the relationship between traffic class and diel period.

Distance to buildings and forest analyses took place only for used and available road crossing locations in Kentucky, as this was the extent of coverage for the buildings and forest polygon shapefiles described previously. I drew 200 random on-road locations from the 100-m buffer surrounding each used and available road crossing location, and, using ArcGIS 9.2 Spatial Analyst, calculated Euclidean distance from these points to the buildings and forest polygon layers. I averaged all such distance values across events within each bear, so that each bear yielded a mean used value and a mean available value. I subjected these means to paired t-tests for all bears pooled and stratified by gender. I tested for differences in the distance values of the two genders using independent two-sample t-tests. Finally, I used 1-way ANOVA tests to investigate whether distance to buildings and forest cover differed significantly by diel period.

I used ArcGIS 9.2 Spatial Analyst to extract elevation values from the NED grid mosaic to the 200 random on-road locations per used and available crossing site described previously. Elevation values were then averaged across events within each bear, yielding one mean used value and one mean available value per bear. I subjected these mean values to paired t-tests for all bears pooled and stratified by gender. I used independent two-sample t-tests to identify differences between genders.

I calculated the mean slope of the 100-m, 500-m, and 1-km buffers surrounding each used and available road crossing location by applying zonal statistics to the mosaicked slope grid and relevant buffer shapefiles using ArcGIS 9.2 Spatial Analyst. Each buffer zone yielded values for slope mean, median, minimum, maximum, range, and standard deviation. For slope, only mean values were considered; however, standard deviation was retained for use in the terrain ruggedness analysis discussed below. I used paired t-tests to compare mean used and available slope values for all bears pooled and stratified by gender at each of the three buffer scales, and independent two-sample t-tests to identify differences between genders.

Previous studies have exposed relationships between terrain ruggedness and animal space use and movement, including where animals cross roads (Chruszcz 2003, Dickson et al. 2005). Numerous approaches have been used to quantify terrain ruggedness. Riley et al. (1999) developed a terrain ruggedness index that measured the elevation difference between adjacent cells in a digital elevation model. Chruszcz et al. (2003) calculated terrain ruggedness with a formula incorporating the density of contour lines and variability of eight cardinal aspects. Dickson et al. (2005) derived “topographic roughness” values for animal movement paths by first identifying the maximum slope of each segment in a path, then averaging across segments. I chose an approach similar to that of Dickson et al. (2005), in which the standard deviation of slope values within each road crossing buffer zone was used as a proxy for terrain ruggedness. I obtained slope standard deviation for each buffer zone from the output of the ArcGIS 9.2 zonal statistics procedure described previously. I used paired t-tests to identify differences between mean used and available terrain ruggedness values across all bears pooled and stratified by gender at each of the three buffer scales. I used two-sample t-tests to identify differences between genders.

Proportions of the different land cover categories (Table 3.4) within each buffer zone were calculated for each used and available road crossing location using Hawth’s Analysis Tools version 3.27 Thematic Raster Summary. I averaged used and available land cover proportions by bear at each of the three buffer scales, and compared the resulting means using Wilcoxon rank-sum tests for all bears pooled and for each gender. I used Wilcoxon Mann-Whitney tests to identify differences between the genders.

Several studies have assessed the influence of curvature of the road in predicting wildlife-vehicle collision sites (Bashore et al. 1985, Gunson and Clevenger 2005). Bashore et al. (1985) reported a negative correlation between deer roadkill sites and the distance at which vehicles are no longer visible from the roadkill site, and posited that straighter sections of road afforded drivers a glimpse of roadside deer and thereby minimized collision risk. Past studies have relied on field calculations of road curvature to complete this analysis. I addressed road curvature using the Hawth’s Analysis Tools version 3.2 Line Metrics function, which calculated the sinuosity of a road segment by dividing its length by the straight-line distance from its endpoints. The advantage of sinuosity is that it can be measured in a GIS environment rather than requiring on-site visits. I intersected the set of roads containing a used or available road crossing location with the 100-m and 500-m buffer zones, then calculated sinuosity of the resulting segments. I used paired t-tests to identify differences between mean used and available sinuosity values for all bears pooled and stratified by gender and traffic class, at both buffer scales. Additionally, I used independent two-sample t-tests to determine whether sinuosity values differed significantly by gender.

Road Mortality

Handheld GPS Error. Roadkill data were collected from 1993-2008 by KDFWR personnel. In most instances, gender, age class, site description, and location coordinates were recorded. I calculated the frequency of roadkill events inside and outside of an estimated core distribution area for the Kentucky black bear, which I adopted from a probability of occupancy map (Frary 2008). Additionally, I calculated the frequency of roadkill events in each gender and age class.

Because roadkill locations were recorded using consumer-grade handheld GPS units (J. Plaxico, KDFWR, pers. comm.), I assumed that locations did not represent the exact points of bear-vehicle collisions, but rather, points within a predictable distance of collisions. Factors affecting positional accuracy of handheld GPS units include terrain and canopy characteristics (Wing 2008), satellite configuration (Bolstad et al. 2005), technological differences between unit models (Wing 2008), and user-end considerations such as how the antenna of the GPS unit is oriented (Wing 2008), and how many fixes the user averages at each location (Bolstad et al. 2005). Additionally, prior to May 2000, the U.S. Department of Defense introduced random error to publicly available navigation signals with a feature called selective availability (SA) (Liu 2002).

For point-based measurements such as distance to forest cover and distance to buildings, I felt it important to account for handheld GPS error. Thus, I buffered my post-SA roadkills by a distance of 25 m, which encompassed the average error reported for most consumer-grade handheld GPS units tested in a variety of habitat and terrain types (Johnson and Barton 2004, Bolstad et al. 2005, Wing and Eklund 2007, Wing 2008), and my SA roadkills by 100 m, the reported upper limit of positional error during SA (Liu and Brantigan 1995, Liu 2002). The remaining road mortality variables were measured at scales ranging from 100 m to the total length of the road. For these variables, I felt that handheld GPS error would play only a negligible role; thus, I used the roadkill locations given by KDFWR.

Site Attributes. At each roadkill location or in the surrounding error buffer, I measured the following variables: traffic class, distance to buildings, distance to forest cover, elevation, slope, terrain ruggedness, land cover composition, and road sinuosity. Traffic class was measured at the whole-road scale, with roadkill sites assigned the traffic classes of the roads on which they lay. Distance to buildings and forest cover were measured from on-road random locations within error buffers, and elevation from on-road random locations within a 100-m buffer of roadkill sites. The remaining variables were measured within buffers of 100-m, 500-m, and 1-km surrounding roadkill sites. For each set of measurements associated with an actual roadkill site, there was an accompanying set of measurements obtained from available sites. Available measurements of distance to buildings and forest cover were taken from on-road locations drawn randomly from 1-km buffer zones surrounding roadkills. Available measurements of the remaining variables were taken at 810 random on-road locations, or 30 available sites per actual site drawn from the same county as the roadkill.

I analyzed traffic class across all used and available locations, rather than by roadkill event or county. I tallied occurrences of the four traffic classes within the used and available roadkill samples, then compared observed and expected frequencies for each class using Chi-square goodness-of-fit tests.

As distance to buildings and forest were point-based measurements, they were calculated from random on-road locations within GPS error buffers, rather than from KDFWR-given roadkill sites. I drew 200 random locations from the 100-m error buffer surrounding each pre-SA roadkill, and 50 random locations from the 25-m error buffer surrounding each post-SA roadkill. I calculated the Euclidean distance from each error buffer location to the buildings and forest polygon shapefiles discussed previously, and averaged these measurements to produce one distance to buildings and one distance to forest value per "used" roadkill site. Additionally, I calculated distance to buildings and forest from 2000 random on-road locations drawn from a 1-km buffer surrounding each roadkill, and averaged these to produce mean "available" values per site. Although limiting statistical analysis to a 1-km scale restricts consideration of where bears are most likely to be killed by vehicles, it allows for local assessments of the influence of built structures and forest cover on roadkill probability, when other variables (traffic volume, road width, topographical attributes) are held relatively equal. I compared used and mean available distance values associated with each roadkill event using paired t-tests.

I calculated elevation within 100-m buffers surrounding roadkill sites and associated available sites. Adopting methodologies used in the road crossing site analyses, I drew 200 random on-road locations within each 100-m buffer, and extracted elevation values from the NED grid mosaic to these points using ArcGIS 9.2 Spatial Analyst. I averaged elevation values within the buffer surrounding each used roadkill site, and across the buffers surrounding the associated set of available sites, and compared the resulting means using paired t-tests.

I calculated the mean slope and terrain ruggedness values of the 100 m, 500 m, and 1 km buffers surrounding each used roadkill location and associated set of available locations. Measurements were taken by applying zonal statistics to the slope grid mosaic and relevant buffer shapefiles in ArcGIS 9.2 Spatial Analyst. The output gave values for slope mean and standard deviation. Mean values were used as slope, and standard deviation values as terrain ruggedness. I averaged slope and terrain ruggedness values across the set of available sites associated with a particular roadkill event within each buffer scale, then compared used and mean available values using paired t-tests stratified by buffer scale.

Proportions of the different land cover categories (Table 3.4) within each buffer zone were calculated for used and available roadkill sites using Hawth's Analysis Tools version 3.27 Thematic Raster Summary. I compared proportions at used sites with mean proportions at corresponding available sites using Wilcoxon rank-sum tests stratified by buffer scale.

To calculate road sinuosity, I first intersected the set of roads containing a used or available roadkill site with the 100-m and 500-m buffer zones surrounding each used or available roadkill. I calculated sinuosity of the resulting segments using Hawth's Analysis Tools version 3.27 Line Metrics. I used paired t-tests to compare sinuosity at used and corresponding available roadkill sites, and independent two-sample t-tests to compare sinuosity of used and available roadkill sites within each traffic class, pooled across all roadkill events. Analyses were conducted at both buffer scales.

I compared the relative frequencies of the 4 traffic classes between roadkill and road crossing samples using Chi-square goodness-of-fit tests. I dropped those traffic classes that were underrepresented in the roadkill sample from the road crossing sample, so that additional comparisons between roadkill and road crossing events could be made, controlling for traffic class. Because females accounted for only 1 of 27 roadkills, I limited subsequent analyses to male bears. I compared distance to forest, distance to buildings, elevation, and sinuosity of roadkill and road crossing sites using independent two-sample t-tests. Elevation analysis was undertaken using only those roadkills occurring in counties for which I had road crossing data. I compared land cover composition of roadkill and road crossing sites using Wilcoxon Mann-Whitney tests.

Table 3.1. Standard deviation of hourly movement rates of black bears averaged by week, southeastern Kentucky, 2005-08.

ID	Sex	Standard deviation
1	F	38.9
3	F	101
5	F	56.7
12	M	86.6
28	M	108
31	F	58.0
37	F	57.5
39	F	77.9
44	M	131
61	M	143
68	F	109
74	F	73.2
76	F	57.1
77	M	100.5
78	M	93.6
83	M	198
93	F	47.0
Mean	F	67.7
Mean	M	123

Table 3.2. Calculations used to define black bear denning start and end dates, southeastern Kentucky, 2005-08.

ID	Sex	Den type	Low[a]	StDev[b]	*d*-value[c]	Start date[d]	End date
1	F	natal	2.98	67.7	70.6	N/A	4-May
1	F	yearling	0	67.7	67.7	2-Dec	24-Mar
3	F	natal	2.1	67.7	69.8	N/A	21-Apr
3	F	yearling	35.8	67.7	103	2-Dec	4-May
5	F	natal	0.86	67.7	68.5	N/A	6-Jun
5	F	yearling	0	67.7	67.7	23-Dec	14-Apr
12	M	male	2.87	123	126	4-Nov	16-May
28	M	male	18.0	123	141	11-Nov	21-Apr
31	F	natal	1.58	67.7	69.2	23-Dec	N/A
37	F	yearling	25.5	67.7	93.1	27-Jan	3-Mar
39	F	natal	0	67.7	67.7	4-Nov	6-Jun
44	M	male	1.82	123	125	6-Jan	14-Apr
61	M	male	2.5	123	126	23-Dec	7-Apr
68	F	natal	0	67.7	67.7	16-Dec	N/A
74	F	natal	0.13	67.7	67.8	23-Dec	N/A
76	F	natal	2.84	67.7	70.5	25-Nov	N/A
77	M	male	4.94	123	128	6-Jan	N/A
78	M	male	4.01	123	127	6-Jan	N/A
83	M	male	1.25	123	124	6-Jan	N/A
Mean	F	natal				6-Dec	17-May

Table 3.2 (continued).

Mean	F	yearling	22-Dec	3-Apr
Mean	M	male	19-Dec	22-Apr

[a] Lowest mean hourly movement rate of the winter (averaged by week)

[b] Average standard deviation of mean hourly movement rates for each gender

[c] *d*-value = lowest mean hourly movement rate + average standard deviation for gender

[d] Start and end dates for each animal represent the midpoint of the start and end week obtained using the *d*-value method.

Table 3.3. Reclassification of the National Landover Classification Database categories used in the Kentucky black bear study 2005-08.

Old category	New category
Developed, open space	Developed
Developed, low intensity	
Developed, medium intensity	
Developed, high intensity	
Barren land	Open, undeveloped
Scrub/shrub	
Grasslands/herbaceous	
Deciduous forest	Forest
Evergreen forest	
Mixed forest	
Pasture/hay	Agricultural
Cultivated crops	
Open water	Water/wetland
Woody wetland	
Emergent herbaceous wetland	

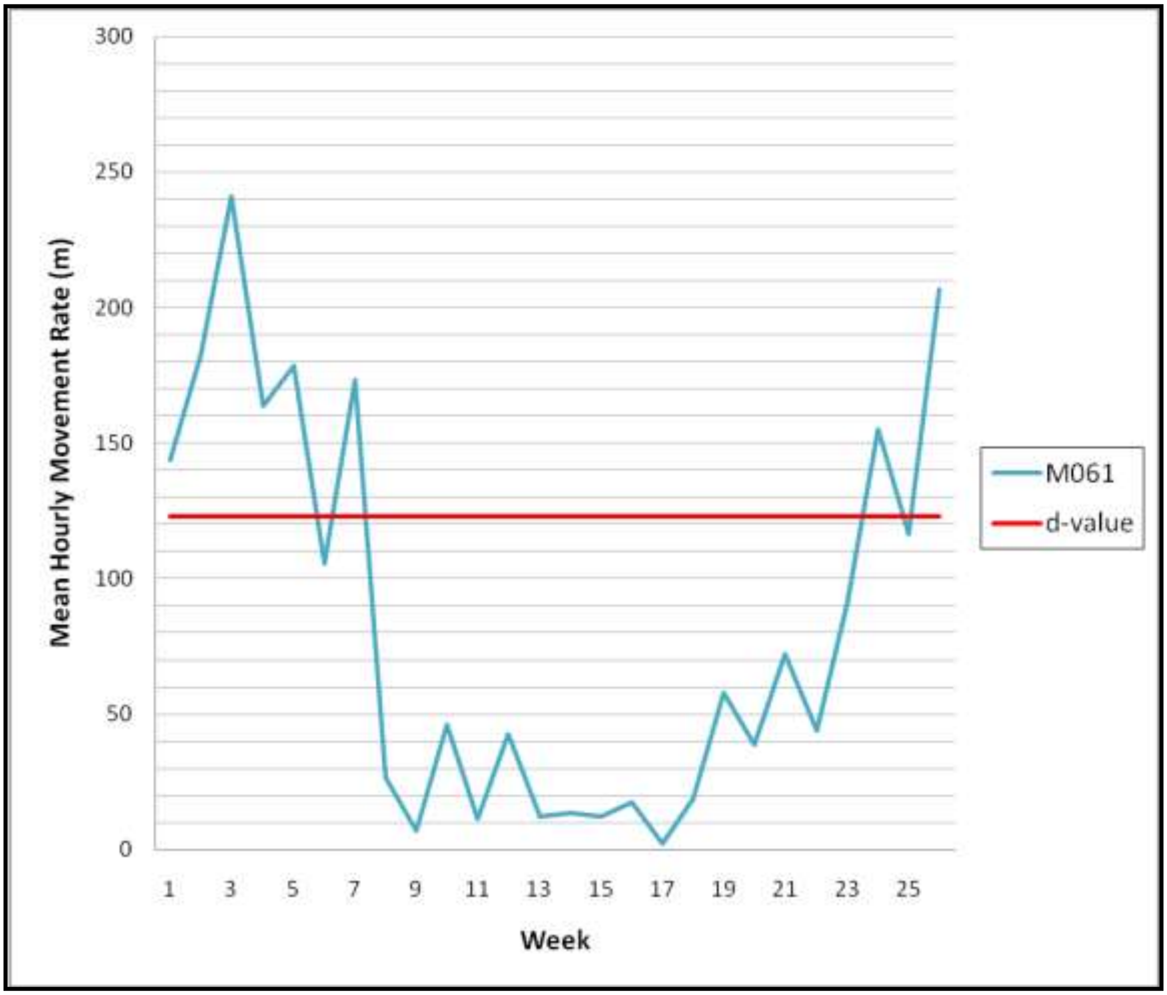


Figure 3.1. Mean hourly movement rates by week of Pine Mountain male black bear M061. The *d*-value indicates start and end of denning period.

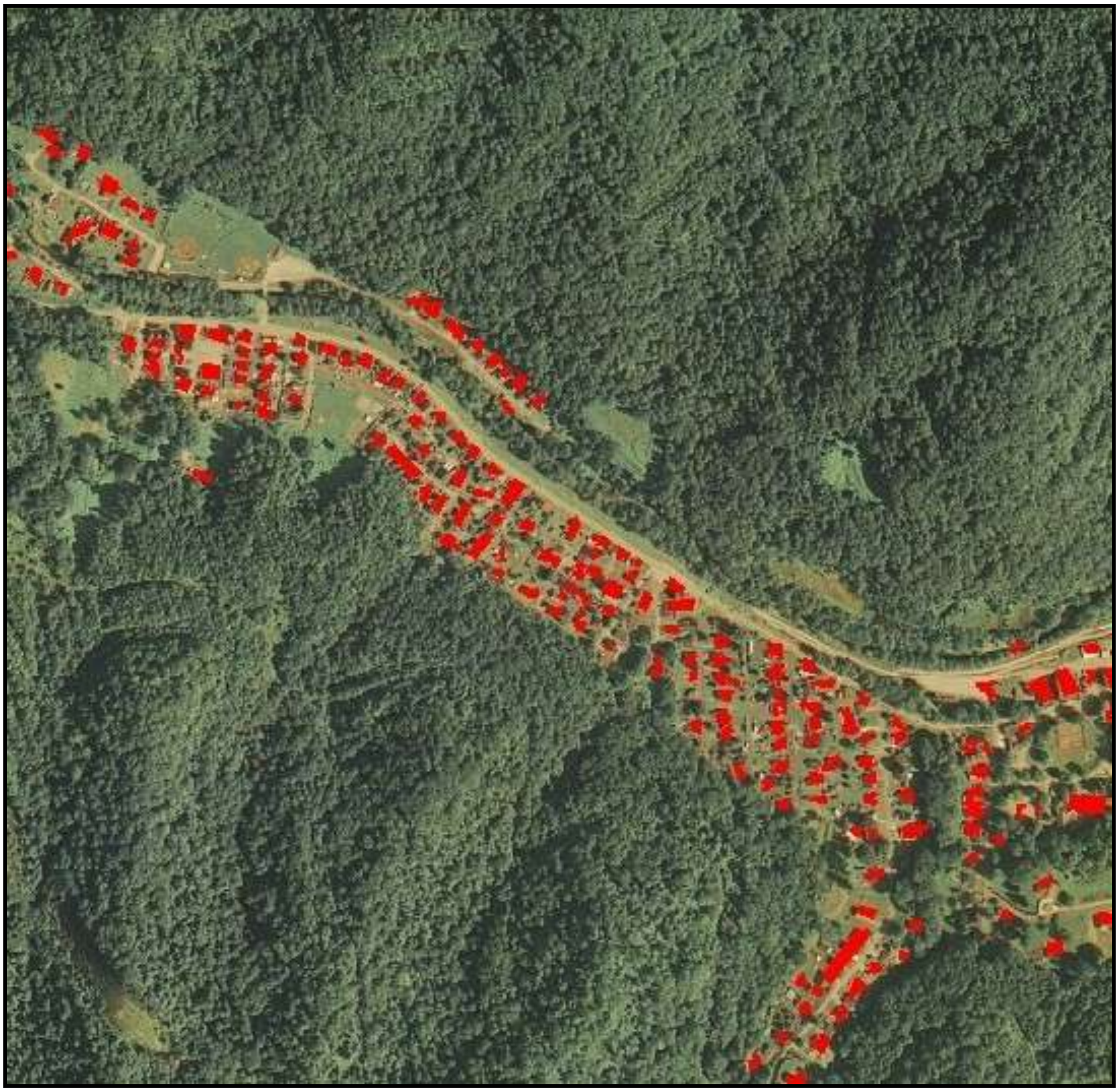


Figure 3.2. Buildings in southeastern Kentucky extracted from orthoimagery into a polygon shapefile using Feature Analyst 4.2 (Visual Learning Systems, Missoula, MT) and used in the black bear study 2005-08.

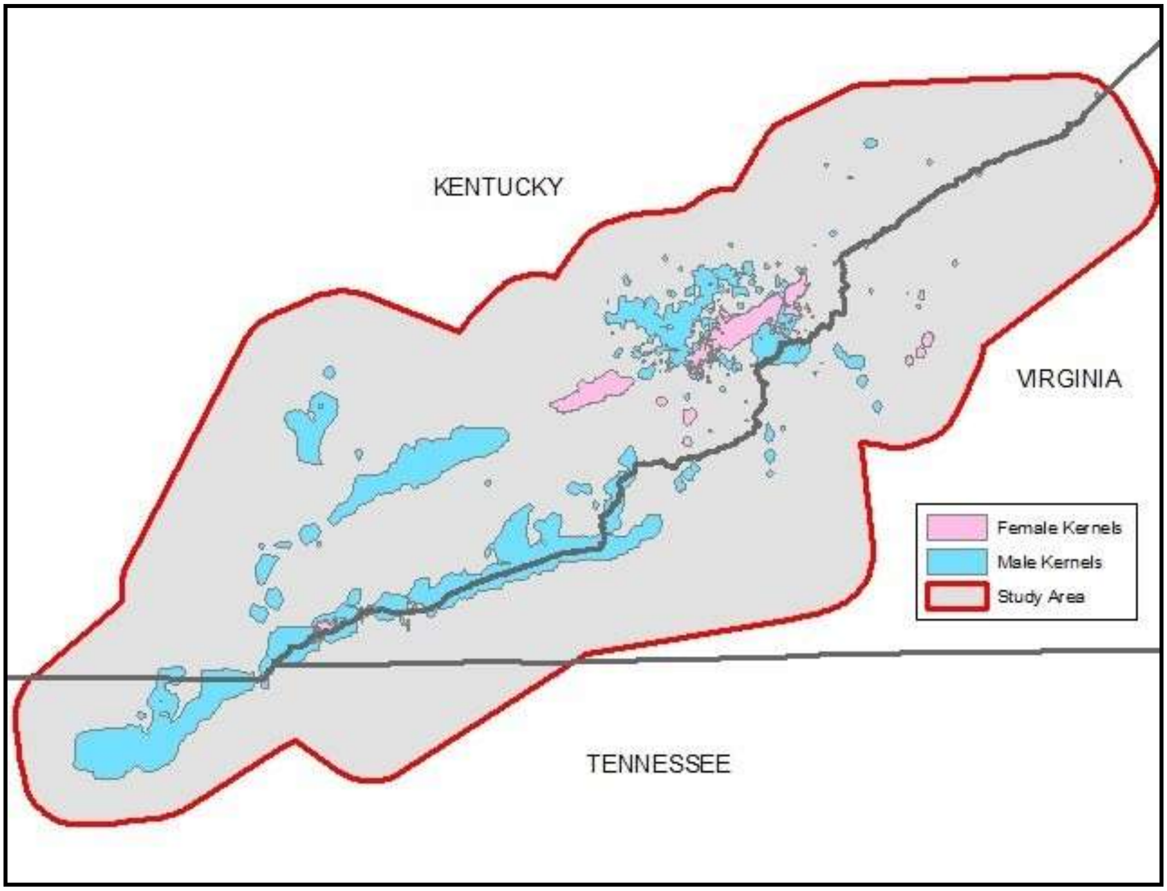


Figure 3.3. Study area for road density analyses, with 95% fixed kernel home ranges for male and female black bears, 2005-08.

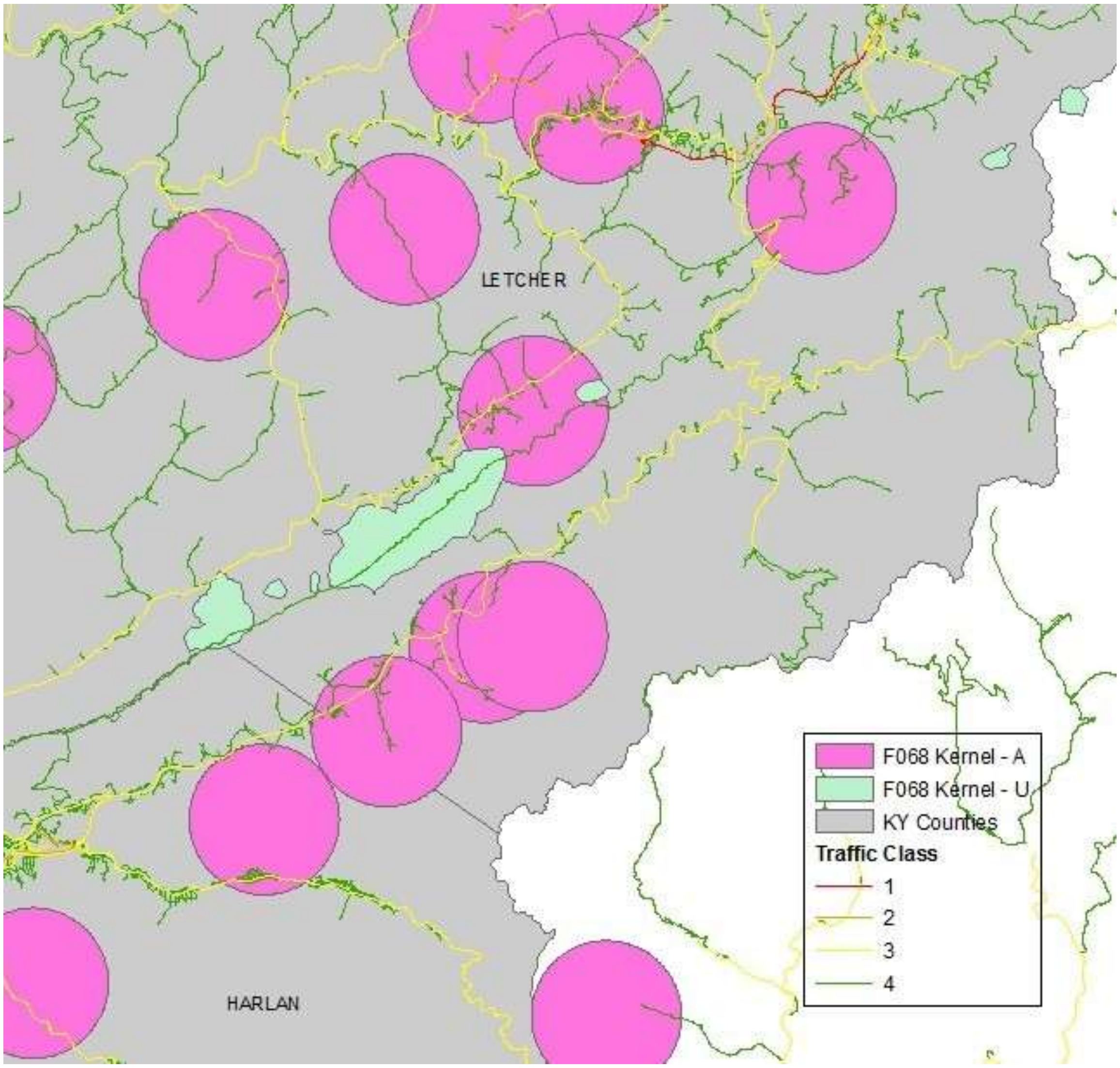


Figure 3.4. 95% fixed kernel home range (U) and associated "available" home ranges (A) for Pine Mountain female black bear F068, used in road density analyses.

CHAPTER 4

RESULTS

Bear Captures

From 18 May 2005 through 16 August 2008, 32 bears (12F, 20M) were captured and fitted with GPS collars. Eleven (3F, 8M) were captured on Cumberland Mountain, and the remaining 21 (9F, 12M) on or near Pine Mountain. Captured bears averaged 4.4 years of age and ranged from 2-12 years. Location data were retrieved for 31 of 32 bears. M011, M015, M075 provided < 30 days of location data, and were excluded from analyses. The collar of M030 stopped emitting a VHF signal, and could not be retrieved for data upload. The 28 remaining bears (12F, 16M) provided location data for an average of 263 days and ranged from 51-643 days (Appendix A).

Road Avoidance

Road Density. Twenty-four bears (11F, 13M) provided data from at least 2 active seasons, and were retained for the road density analyses. Average 95% fixed kernel home range size was 86.0 km^2 for males and 15.0 km^2 for females; average 50% fixed kernel core use area size was 4.2 km^2 for males and 0.80 km^2 for females (Appendix B). Average road density of 95% kernels was 0.78 km/km^2. Average 95% kernel road density for males was 0.73 km/km^2, for females 0.85 km/km^2, for Pine Mountain bears 1.03 km/km^2, and for Cumberland Mountain bears 0.18 km/km^2. Average road density of 50% kernel core use areas was 0.38 km/km^2. Average 50% kernel road density for males was 0.50 km/km^2, for females 0.24 km/km^2, for Pine Mountain bears 0.53 km/km^2, and for Cumberland Mountain bears 0.007 km/km^2 (Tables 4.1-4.4).

Density of the overall road network and of high and low traffic roads were lower than expected in 95% fixed kernel home ranges ($t_{23} = -3.20$, $P = 0.004$, all roads; $t_{23} = -16.07$, $P < 0.001$, high traffic; and $t_{23} = -3.53$, $P = 0.002$, low traffic). Male 95% kernels had overall road densities and very high, high, and low traffic road densities lower than expected ($t_{12} = -2.65$, $P = 0.02$, all roads; $t_{12} = -2.53$, $P = 0.03$, very high traffic; $t_{12} = -16.70$, $P < 0.001$, high traffic; and $t_{12} = -3.02$, $P = 0.01$, low traffic). Overall road densities of female and Pine Mountain 95% kernels were not different from random; however, high traffic road densities were lower than expected ($t_{10} = -9.31$, $P < 0.001$, female; $t_{16} = -14.83$, $P < 0.001$, Pine Mountain). Road densities of all traffic classes within 95% kernels of Cumberland Mountain bears were lower than expected ($t_6 = -10.25$, $P < 0.001$, all roads; $t_6 = -3.10$, $P = 0.02$, very high traffic; $t_6 = -7.25$, $P < 0.001$, high traffic; $t_6 = -7.68$, $P < 0.001$, moderate traffic; and $t_6 = -11.19$, $P < 0.001$, low traffic).

Overall road densities and densities of all road classes were lower than expected in 50% fixed kernel core use areas ($t_{23} = -5.72$, $P < 0.001$, all roads; $t_{23} = -2.55$, $P = 0.02$, very high traffic; $t_{23} = -8.87$, $P < 0.001$, high traffic; $t_{23} = -3.27$, $P = 0.003$, moderate traffic; and $t_{23} = -5.05$, $P < 0.001$, low traffic). Both males and females occupied core areas with overall road densities lower than expected ($t_{12} = -3.04$, $P = 0.01$, males; $t_{10} = -6.09$, $P < 0.001$, females). Core areas of male bears had lower than expected densities of very high, high, and low traffic roads ($t_{12} = -4.02$, $P = 0.002$, very high traffic; $t_{12} = -7.20$, $P < 0.001$, high traffic; and $t_{12} = -2.81$, $P = 0.02$, low traffic). Core areas of female bears had lower than expected densities of high, moderate, and low traffic roads ($t_{10} = -6.68$, $P < 0.001$, high traffic; $t_{10} = -8.95$, $P < 0.001$, moderate traffic; and $t_{10} = -4.88$, $P = 0.001$, low traffic). The core areas of Pine Mountain bears had densities of the overall road network and high and low traffic roads lower than expected ($t_{16} = -3.52$, $P = 0.003$, all roads; $t_{16} = -7.45$, $P < 0.001$, high traffic; and $t_{16} = -2.99$, $P = 0.009$, low traffic). The core areas of Cumberland Mountain bears had densities of the overall road network and all traffic classes lower than expected ($t_6 = -14.75$, $P < 0.001$, all roads; $t_6 = -2.65$, $P = 0.04$, very high traffic; $t_6 = -4.60$, $P = 0.004$, high traffic; $t_6 = -6.73$, $P < 0.001$, moderate traffic; and $t_6 = -21.27$, $P < 0.001$, low traffic).

High traffic roads accounted for a smaller proportion of the road network than expected in the 95% and 50% kernels of pooled and Pine Mountain bears ($S_{20} = -106.5$, $P < 0.001$, 95% pooled; $S_{10} = -33$, $P = 0.001$, 50% pooled; $S_{16} = -76.5$, $P < 0.001$, 95% Pine Mountain; $S_9 = -27.5$, $P = 0.002$, 50% Pine Mountain), and in the 95% kernels of both genders ($S_{11} = -33$, $P = 0.007$, male; $S_8 = -22.5$, $P = 0.004$, female). Males had core use areas with very high and high traffic roads underrepresented relative to what was expected by chance ($S_7 = -10.5$, $P = 0.03$, very high traffic; $\mathrm{S}_7 = -18$, $P = 0.008$, high traffic), whereas female 50% kernels included all traffic classes at proportions not different from random. Cumberland Mountain bears included all traffic classes at proportions not different from random in their 95% kernels; I did not analyze road network composition for the 50% kernels of Cumberland Mountain bears because only one such core area contained roads.

Neither road densities nor road network composition of male and female kernels differed. Cumberland Mountain bears occupied 95% kernels with overall road densities and densities of moderate and low traffic roads lower than those of Pine Mountain ($t_{22} = -4.05$, $P < 0.001$, all roads; $t_{19.1} = -4.15$, $P < 0.001$, moderate traffic; and $t_{22} = -4.31$, $P <$

0.001, low traffic), and 50% kernels with densities of low traffic roads lower than those of Pine Mountain ($t_{16.1} = -3.01$, $P = 0.008$). Additionally, moderate traffic roads accounted for a smaller proportion of the road network in the 95% kernels of Cumberland Mountain bears than in the 95% kernels of Pine Mountain bears ($z_{19} = -2.02$, $P = 0.04$).

Road densities of all traffic classes differed between the 50% and 95% kernels of pooled bears ($t_{23} = -3.22$, $P = 0.004$, all roads; $t_{23} = -2.52$, $P = 0.02$, high traffic; $t_{23} = 2.69$, $P = 0.01$, moderate traffic; and $t_{23} = -2.48$, $P = 0.02$, low traffic). Males had lower densities of high traffic roads in their 50% kernels than in their 95% kernels ($t_{12} = -2.42$, $P = 0.03$), while females had lower densities of the overall road network and moderate traffic roads in their 50% kernels than in their 95% kernels ($t_{10} = -2.80$, $P = 0.02$, all roads; $t_{10} = -2.67$, $P = 0.02$, moderate traffic). Pine Mountain bears had lower densities of the overall road network and high, moderate, and low traffic roads in their 50% kernels than in their 95% kernels ($t_{17} = -3.14$, $P = 0.006$, all roads; $t_{17} = -2.28$, $P = 0.04$, high traffic; $t_{17} = -2.75$, $P = 0.01$, moderate traffic; and $t_{17} = -2.31$, $P = 0.03$, low traffic), while road densities in the 50% and 95% kernels of Cumberland Mountain bears did not differ.

Eight Pine Mountain females provided sufficient data for analysis of road density patterns by reproductive phase. Females that were pregnant or caring for cubs of the year occupied 95% kernels in which very high traffic roads were less dense and comprised a smaller proportion of the road network than expected ($t_5 = -3.32$, $P = 0.02$, density; $S_5 = -10.5$, $P = 0.03$, proportion). Females caring for yearling cubs or breeding occupied 95% kernels in which road densities and road network composition were not different from random. The 50% kernels of females pregnant or caring for cubs of the year had lower than expected densities of the overall road network and moderate and low traffic roads (t_5

= -5.44, $P = 0.003$, all roads; $t_5 = -2.95$, $P = 0.03$, moderate traffic; and $t_5 = -3.84$, $P = 0.01$, low traffic), while the 50% kernels of females caring for yearlings or breeding had lower than expected densities of high and moderate roads only ($t_6 = -5.63$, $P = 0.001$, high traffic; $t_6 = -13.64$, $P < 0.001$, moderate traffic). Road network composition of 50% kernels was not analyzed by reproductive phase due to insufficient sample size.

I found no differences in road density values between the two female reproductive phases, nor between males and either of the female phases, at either kernel isopleth. However, I found that moderate traffic roads accounted for a smaller proportion, and low traffic roads a larger proportion, of the 95% kernel road networks of females pregnant or caring for cubs of the year than in those of Pine Mountain males ($z_{12} = -2.13$, $P = 0.03$, moderate traffic; $z_{12} = 2.01$, $P = 0.04$, low traffic).

Distance Analyses. Twenty-four bears (11F, 13M) provided data from ≥ 2 active seasons, and were retained for distance analyses (Appendix B). Eight females offered sufficient data for analysis by reproductive phase (Appendix C). Very high traffic roads were disregarded because they occurred in only 7 (29.2%) of the 24 95% MCP home ranges used in this analysis. Bears used habitats farther from roads and buildings during active seasons than expected ($t_{23} = 2.09$, $P = 0.048$, roads, $t_{23} = 3.98$, $P < 0.001$, buildings). Males used habitats farther from the overall road network, low traffic roads, and buildings than expected ($t_{12} = 2.31$, $P = 0.04$, all roads; $t_{12} = 2.21$, $P = 0.047$, low traffic; and $t_{12} = 3.12$, $P = 0.009$, buildings). Females and Pine Mountain bears did not exhibit road avoidance, but were found farther from buildings than expected ($t_{10} = 2.91$, $P = 0.01$, females; $t_{16} = 3.23$, $P = 0.005$, Pine Mountain). Cumberland Mountain bears used habitats farther from the overall road network, moderate and low traffic roads, and buildings than expected ($t_6 = 3.74$, $P = 0.01$, all roads; $t_6 = 4.60$, $P = 0.004$, moderate traffic; $t_6 = 3.65$, $P = 0.01$, low traffic; and $t_6 = 2.61$, $P = 0.04$, buildings) (Table 4.5-4.7).

Avoidance of roads and buildings was not uniform across diel periods. By day, bears were located farther than expected from the overall road network, low traffic roads, and buildings ($t_{23} = 2.34$, $P = 0.03$, all roads, $t_{23} = 2.09$, $P = 0.048$, low traffic; $t_{23} = 5.32$, $P < 0.001$, buildings). During crepuscular and nighttime periods, bears used habitats farther than expected from buildings ($t_{23} = 3.97$, $P < 0.001$, crepuscular; $t_{23} = 2.49$, $P = 0.02$, night), but did not exhibit road avoidance. Males used habitats farther than expected from low traffic roads during the day ($t_{12} = 2.73$, $P = 0.02$), and from the overall road network and buildings during both day and crepuscular periods ($t_{12} = 2.74$, $P = 0.02$, all roads day; $t_{12} = 2.20$, $P = 0.048$, all roads crepuscular; $t_{12} = 4.59$, $P < 0.001$, buildings day; and $t_{12} = 2.83$, $P = 0.02$, buildings crepuscular), but did not avoid roads or buildings at night. Females and Pine Mountain bears used habitats farther than expected from buildings during day and crepuscular periods ($t_{10} = 3.14$, $P = 0.01$, female day; $t_{10} = 3.31$, $P = 0.008$, female crepuscular; $t_{16} = 4.79$, $P < 0.001$, Pine Mountain day; $t_{16} = 3.24$, $P = 0.005$, Pine Mountain crepuscular), but did not exhibit road avoidance during any of the diel periods. Cumberland Mountain bears were located farther than expected from roads during all diel periods ($t_6 = 3.15$, $P = 0.02$, day; $t_6 = 4.00$, $P = 0.007$, crepuscular; $t_6 = 3.25$, $P = 0.02$, night), and used habitats farther than expected from buildings during day and crepuscular periods ($t_6 = 2.60$, $P = 0.04$, day; $t_6 = 2.53$, $P = 0.045$, crepuscular).

Overall, there was a trend of increasing diel variation in road distance with increasing traffic volume ($F_{2,23} = 4.15$, $P = 0.03$), although this pattern was not observed for either of the genders or regions considered separately. Bears were located farther from high traffic roads by day than during nighttime or crepuscular hours ($F_{1,23} = 7.04$, $P = 0.01$, day vs. night; $F_{1,23} = 8.35$, $P = 0.008$, day vs. crepuscular). Females were located farther from high traffic roads during the day than during the remainder of the 24-hour clock ($F_{1,10} = 5.87$, $P = 0.04$). Pine Mountain bears were located farther from the overall road network and high, moderate, and low traffic roads during the daytime than during the remainder of the 24-hour clock ($F_{1,16} = 4.84$, $P = 0.04$, all roads; $F_{1,16} = 6.06$, $P = 0.03$, high traffic; $F_{1,16} = 7.91$, $P = 0.01$, moderate traffic; and $F_{1,16} = 4.81$, $P = 0.04$, low traffic). Pine Mountain bears used habitats farther from buildings during the day than during nighttime or crepuscular hours ($F_{1,16} = 11.89$, $P = 0.003$, day vs. night; $F_{1,16} = 12.01$, $P = 0.003$, day vs. crepuscular), and during crepuscular hours than at night ($F_{1,16} = 7.16$, $P = 0.02$). Males and Cumberland Mountain bears did not exhibit diel variation in distance to roads or buildings.

Females used habitats farther from high traffic roads and closer to moderate traffic roads than males ($t_{22} = 2.24$, $P = 0.04$, high traffic; $t_{16.4} = -2.76$, $P = 0.01$, moderate traffic). Cumberland Mountain bears were located farther from the entire road network, moderate and low traffic roads, and buildings than Pine Mountain bears ($t_{7.02} = 6.62$, $P < 0.001$, all roads; $t_{7.12} = 3.55$, $P = 0.009$, moderate traffic; $t_{7.26} = 6.90$, $P < 0.001$, low traffic; $t_{22} = 8.79$, $P < 0.001$, buildings). However, Cumberland Mountain bears were located closer to high traffic roads than Pine Mountain bears ($t_{20.5} = -4.18$, $P < 0.001$).

Road Crossing

Mean 50% CEP of the four cover types tested weighted by the proportion of each cover type in the study area was 24.7 m. Following removal of bear locations within this distance of roads and querying path segments 4 hours or less in duration, 27 bears (11F, 16M) had at least one road crossing. Twenty-one bears (9F, 12M) had the minimum required 30 crossings. Because only two Cumberland Mountain bears (M087 and M094) met these criteria, I limited road crossing analysis to 19 Pine Mountain bears (Table 4.8).

Males had a road crossing rate of 1.78 events/day ($n = 10$, SD = 0.78), which was 2.3 times as high as the rate of 0.77 events/day I obtained for females ($n = 9$, SD=0.60) ($t_{17} = 3.13$, $P = 0.006$). The average daily crossing rate of females caring for yearling cubs was 1.04 events/day ($n = 6$, SD = 0.64), 15.5% higher than the rate of 0.90 events/day I found for females with cubs of the year ($n = 6$, SD = 0.56).

The four traffic classes were not represented at their expected frequencies in the full sample of road crossing events, nor in events stratified by gender ($\chi^2_3 = 160.53$, $P < 0.001$, all bears; $\chi^2_3 = 91.66$, $P < 0.001$, female; $\chi^2_3 = 75.83$, $P < 0.001$, male) (Figures 4.1-4.2). Moderate traffic roads accounted for a lower proportion of pooled crossing events than expected, and low traffic roads a higher proportion ($S_{18} = -65.5$, $P = 0.003$, moderate traffic; $S_{18} = 69.5$, $P = 0.001$, low traffic). Males and females crossed low traffic roads at higher relative frequencies than expected ($S_9 = 21.5$, $P = 0.03$, male; $S_8 = 15$, $P = 0.04$, female), and males crossed moderate traffic roads at lower relative frequencies than expected ($S_9 = -19.5$, $P = 0.049$). Females caring for yearling cubs or breeding crossed low traffic roads at higher relative frequencies than expected ($S_6 = 14$, $P = 0.02$), and moderate traffic roads at lower relative frequencies than expected ($S_6 = -14$, $P = 0.02$). Females pregnant or caring for cubs of the year did not exhibit selectivity or avoidance of any of the traffic classes.

Road crossings took place during crepuscular hours at higher relative frequencies than expected ($S_{18} = 76$, $P = 0.002$). Further analysis indicated this trend was true only for males and low traffic roads ($S_9 = 23.5$, $P = 0.01$, male, all roads; $S_9 = 24.5$, $P = 0.01$, male, low traffic). Road crossings took place during nighttime hours at lower relative frequencies than expected, both for all roads and low traffic roads ($S_{18} = -56$, $P = 0.02$, all roads; $S_{18} = -62$, $P = 0.01$, low traffic). As traffic volume increased, bears were increasingly likely to cross roads during night or crepuscular hours than during the day ($\chi^2_3 = 7.98$, $P = 0.047$). However, this trend was not evident for either of the genders (Figures 4.3-4.4).

Pooled bears and females crossed roads farther from buildings and closer to forest than expected ($t_{18} = 6.98$, $P < 0.001$, pooled buildings; $t_{18} = -2.67$, $P = 0.02$, pooled forest; $t_8 = 4.42$, $P = 0.02$, female buildings; $t_8 = -2.34$, $P = 0.048$, female forest). Males crossed roads farther from buildings than expected ($t_9 = 5.35$, $P < 0.001$), but at distances from forest not different from random (Table 4.9). I found no overall difference between male and female road crossing sites in the proximity to buildings and forest; however, females crossed farther from buildings than males during the day ($t_{15} = 2.38$, $P=0.03$, equal variances). Bears with sufficient crossing data in the three diel periods crossed roads closer to buildings at night than in the day ($F_{1,16} = 4.58$, $P = 0.048$), and closer to buildings at night than in pooled day and crepuscular periods ($F_{1,16} = 5.02$, $P = 0.04$). However, I detected no diel variation in proximity to buildings for either of the genders. Proximity to forest did not vary by diel period for pooled bears, males, or females.

Pooled bears, females, and males crossed roads at higher elevations than expected ($t_{18} = 6.46$, $P < 0.001$, pooled; $t_8 = 3.70$, $P = 0.006$, female; $t_9 = 5.33$, $P < 0.001$, male), and females crossed at higher elevations than males ($t_{17} = 2.20$, $P = 0.04$). Mean slope was higher than expected at the 100-m scale for pooled bear and female road crossing sites ($t_{18} = 2.72$, $P = 0.01$, pooled; $t_8 = 2.55$, $P = 0.03$, female), and at the 500-m scale for female crossing sites only ($t_8 = 2.74$, $P = 0.03$). I did not detect a difference between mean slopes at male and female crossing sites. Females crossed roads where terrain ruggedness was lower than expected at the 1-km scale ($t_8 = -4.01$, $P = 0.004$), but the crossing sites of males and pooled bears had terrain ruggedness values not different from random (Table 4.9). I did not detect a difference between mean terrain ruggedness values at male and female crossing sites.

At all three buffer scales, pooled bears, males, and females crossed roads where forested land was more prevalent than expected ($S_{18} = 85$, $P < 0.001$, 100-m; $S_{18} = 85$, $P < 0.001$, 500-m; $S_{18} = 77$, $P = 0.001$, 1-km pooled bears; $S_9 = 26.5$, $P = 0.004$, 100-m; $S_9 = 26.5$, $P = 0.004$, 500-m; $S_9 = 23.5$, $P = 0.01$, 1-km males; $S_8 = 18.5$, $P = 0.03$, 100-m; $\mathrm{S}_8 = 20.5$, $P = 0.01$, 500-m; $S_8 = 17.5$, $P = 0.04$, 1-km females), and where open land was less prevalent than expected ($S_{18} = -87$, $P < 0.001$, 100-m; $S_{18} = -93$, $P < 0.001$, 500-m; $S_{18} = -85$, $P < 0.001$, 1-km pooled bears; $S_9 = -27.5$, $P = 0.002$, 100-m; $S_9 = -26.5$, $P = 0.004$, 500-m; $S_9 = -26.5$, $P = 0.004$, 1-km males; $S_8 = -17.5$, $P = 0.004$, 100-m; $S_8 = -22.5$, $P = 0.004$, 500-m; $S_8 = -17.5$, $P = 0.004$, 1-km females). Additionally, at all three buffer scales, pooled bears and males crossed roads where agricultural land was less prevalent than expected ($S_{18} = -62$, $P = 0.01$, 100-m; $S_{18} = -82$, $P < 0.001$, 500-m; $S_{18} = -75$, $P = 0.001$, 1-km pooled; $S_9 = -24.5$, $P = 0.01$, 100-m; $S_9 = -26.5$, $P = 0.004$, 500-m; $S_9 = -24.5$, $P = 0.001$, 1-km males). At the two larger scales of analysis, pooled bears crossed roads where open water and wetlands were more prevalent than expected ($S_{18} = 60$, $P = 0.01$, 500-m; $S_{18} = 58$, $P = 0.02$, 1-km). Males crossed roads where open water and wetlands were more prevalent than expected at the two smaller scales of analysis (S_9

= 17.5, $P = 0.04$, 100-m; $S_9 = 21.5$, $P = 0.03$, 500-m). Developed land was less prevalent than expected at the crossing sites of pooled bears ($S_{18} = -55$, $P = 0.03$, 100-m; $S_{18} = -56$, $P = 0.02$, 500-m; $S_{18} = -57$, $P = 0.02$, 1-km pooled), but was present in proportions not different from random at crossing sites analyzed by gender (Table 4.9). I detected no difference between land cover composition at the crossing sites of males and females.

Roads crossed by bears were more sinuous at the 100-m scale than what was expected by random chance ($t_{18} = 2.29$, $P = 0.03$); however, neither males nor females had sinuosity values different from random at either the 100-m or 500-m buffer scale (Table 4.9). Stratifying by traffic class, bears crossed moderate and low traffic roads where sinuosity was not different from random; I could not analyze the two highest traffic categories due to insufficient sample size. I did not detect a difference between sinuosity at the road crossing sites of males and females.

Road Mortality

From 1993 to 2008, 29 bear road mortalities in 14 counties were documented by KDFWR or other agency personnel (Figure 4.5). Roadkills lacking GPS coordinates or with suspected erroneous coordinates were discarded, leaving 27 events available for analysis (Table 4.10). Of these, 22 (81.5%) were male, 1 female (3.7%), and 4 (14.8%) were of unknown gender. Thirteen (48.1%) of the roadkilled animals were subadult or yearling-aged, 9 (33.3%) adult, and 5 (18.5%) of unknown age. Four (14.8%) roadkills were located within the core distribution area, while the remaining 23 (85.2%) were located outside the core area (Figure 4.6).

The four traffic classes were not represented at their expected frequencies in the roadkill sample ($\chi^2_3 = 76.7$, $P < 0.001$). Although available roads were predominantly of the lowest traffic class, roadkills occurred primarily on high and moderate traffic roads. Notably, high traffic roads occurred 8 times as frequently in the roadkill sample as in the available road network. Conversely, low traffic roads occurred 6 times as frequently in the available road network as in the roadkill sample (Figure 4.7).

Roadkills occurred at elevations and distances from buildings and forest cover not different from random. At the 100-m scale, roadkill locations had higher slope values than expected ($t_{25} = 2.35$, $P = 0.03$). No clear patterns of terrain ruggedness were observed at any of the buffer distances. At the 100-m scale, roadkill sites had lower proportions of forested land and higher proportions of developed land than expected ($S_{26} = -128$, $P < 0.001$, forest; $\mathrm{S}_{26} = 110$, $P = 0.006$, developed). Open water and wetlands were present in lower proportions than expected at the 500-m and 1-km scale ($S_{26} = -118$, $P = 0.003$, 500-m; $S_{26} = -83$, $P = 0.04$, 1-km), and agricultural land was less prevalent than expected at the 500-m scale only ($S_{26} = -87$, $P = 0.03$) (Table 4.11).

Roadkills occurred on roads that were less sinuous than expected at the 500-m scale ($t_{26} = -4.61$, $P < 0.0001$). When sinuosity data were analyzed by traffic class, roadkills occurred on very high traffic roads that were less sinuous than expected at the 500-m scale ($t_4 = -7.31$, $P = 0.002$), on high traffic roads that were less sinuous than expected at the 100-m scale ($t_9 = -7.52$, $P < 0.001$), and on moderate traffic roads that were less sinuous than expected at the 100-m and 500-m scales ($t_8 = -3.54$, $P = 0.008$, 100-m; $t_8 = -3.46$, $P = 0.009$, 500-m) (Table 4.11).

The odds ratio of male vs. female roadkill events was 22, which was different from the odds ratio of 2.3 obtained for male vs. female road crossing events ($\chi^2_1 = 5.45$, $P = 0.02$). Relative frequencies of the 4 traffic classes differed between roadkill and road crossing sites (χ^2_3=668.2, $P < 0.001$). As previously discussed, most roadkills occurred on high and moderate traffic roads, while road crossings occurred overwhelmingly on low traffic roads (Figure 4.8). Thus, only those road crossings occurring on high and moderate traffic roads were used for comparisons with roadkills, and analyses were limited to males. Roadkills occurred at lower elevations than did road crossing events ($t_{14.1} = -2.34$, $P = 0.03$), at distances to forest farther than at road crossing sites ($t_{28.2} = 2.09$, $P = 0.045$), at distances from buildings not different from those at road crossing sites, and on roads less sinuous at the 500-m scale than road crossing roads ($t_{30} = -4.40$, $P < 0.001$). Agricultural land was more prevalent at roadkill sites than at road crossings at the 500-m and 1-km scales ($z_{30} = 2.83$, $P = 0.005$, 500-m; $z_{30} = 2.78$, $P = 0.005$, 1-km). Forest was less prevalent at roadkill sites than at road crossing sites at all three scales ($z_{30} = -2.99$, $P = 0.003$, 100-m; $z_{30} = -2.42$, $P = 0.02$, 500-m; $z_{30} = -2.21$, $P = 0.03$, 1-km).

Table 4.1. Road densities within 95% fixed kernel home ranges of black bears in southeastern Kentucky, 2005-08.

			Road density	Road density by traffic class (km/km^2)			
ID	Sex	Region[a]	(km/km^2)	Very high	High	Moderate	Low
1	F	PM	2.36	0	0.03	0.66	1.68
3	F	PM	1.39	0.17	0	0.38	0.84
5	F	PM	0.49	0	0	0.10	0.39
12	M	PM	1.52	0	0.03	0.53	0.97
28	M	PM	1.88	0	0	0.59	1.29
37	F	PM	0.80	0	0	0.17	0.63
39	F	PM	1.12	0.07	0	0.22	0.83
44	M	CM	0.42	0.02	0.03	0.06	0.31
57	M	PM	0.78	0	0	0.15	0.63
61	M	PM	1.03	0	0.01	0.26	0.76
68	F	PM	0.80	0	0	0.02	0.77
71	F	PM	0.95	0	0	0	0.95
74	F	CM	0	0	0	0	0
76	F	CM	0	0	0	0	0
77	M	CM	0	0	0	0	0
78	M	CM	0.07	0	0	0	0.07
82	F	PM	0.33	0	0	0	0.33
83	M	PM	0.93	0.07	0.02	0.30	0.54

Table 4.1 (continued).

85	M	PM	0.47	0	0	0.04	0.42
86	M	PM	1.08	0	0	0.18	0.89
87	M	CM	0.63	0.01	0.002	0.11	0.50
91	M	PM	0.56	0	0.01	0.15	0.39
93	F	PM	1.07	0	0	0.52	0.54
94	M	CM	0.17	0	0	0	0.17

[a] PM=Pine Mountain, CM=Cumberland Mountain

Table 4.2. Group mean road densities within 95% fixed kernel home ranges of black bears in southeastern Kentucky, 2005-08.

		Road density (km/km^2)		Road density by traffic class (km/km^2)							
				Very high		High		Moderate		Low	
Grp[a]	N	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
M	13	0.73	0.56	0.008	0.02	0.008	0.01	0.18	0.19	0.53	0.37
F	11	0.84	0.68	0.02	0.05	0.003	0.01	0.19	0.23	0.63	0.47
PM	17	1.03	0.52	0.02	0.05	0.006	0.01	0.25	0.21	0.76	0.35
CM	7	0.18	0.25	0.004	0.007	0.005	0.01	0.02	0.05	0.15	0.19
All	24	0.78	0.60	0.01	0.04	0.006	0.01	0.18	0.21	0.58	0.42

[a] M=male, F=female, PM=Pine Mountain, CM=Cumberland Mountain

Table 4.3. Road densities within 50% fixed kernel core use areas of black bears in southeastern Kentucky, 2005-08.

ID	Sex	Region[a]	Road density (km/km^2)	Road density by traffic class (km/km^2) Very high	High	Moderate	Low
1	F	PM	0	0	0	0	0
3	F	PM	0.70	0.17	0	0	0.53
5	F	PM	0	0	0	0	0
12	M	PM	1.78	0	0	1.07	0.71
28	M	PM	1.69	0	0	0.43	1.26
37	F	PM	0.54	0	0	0	0.54
39	F	PM	0	0	0	0	0
44	M	CM	0	0	0	0	0
57	M	PM	0.92	0	0	0	0.92
61	M	PM	0	0	0	0	0
68	F	PM	0	0	0	0	0
71	F	PM	0	0	0	0	0
74	F	CM	0	0	0	0	0
76	F	CM	0	0	0	0	0
77	M	CM	0	0	0	0	0
78	M	CM	0	0	0	0	0
82	F	PM	0	0	0	0	0
83	M	PM	0.02	0	0	0	0.02

Table 4.3 (continued).

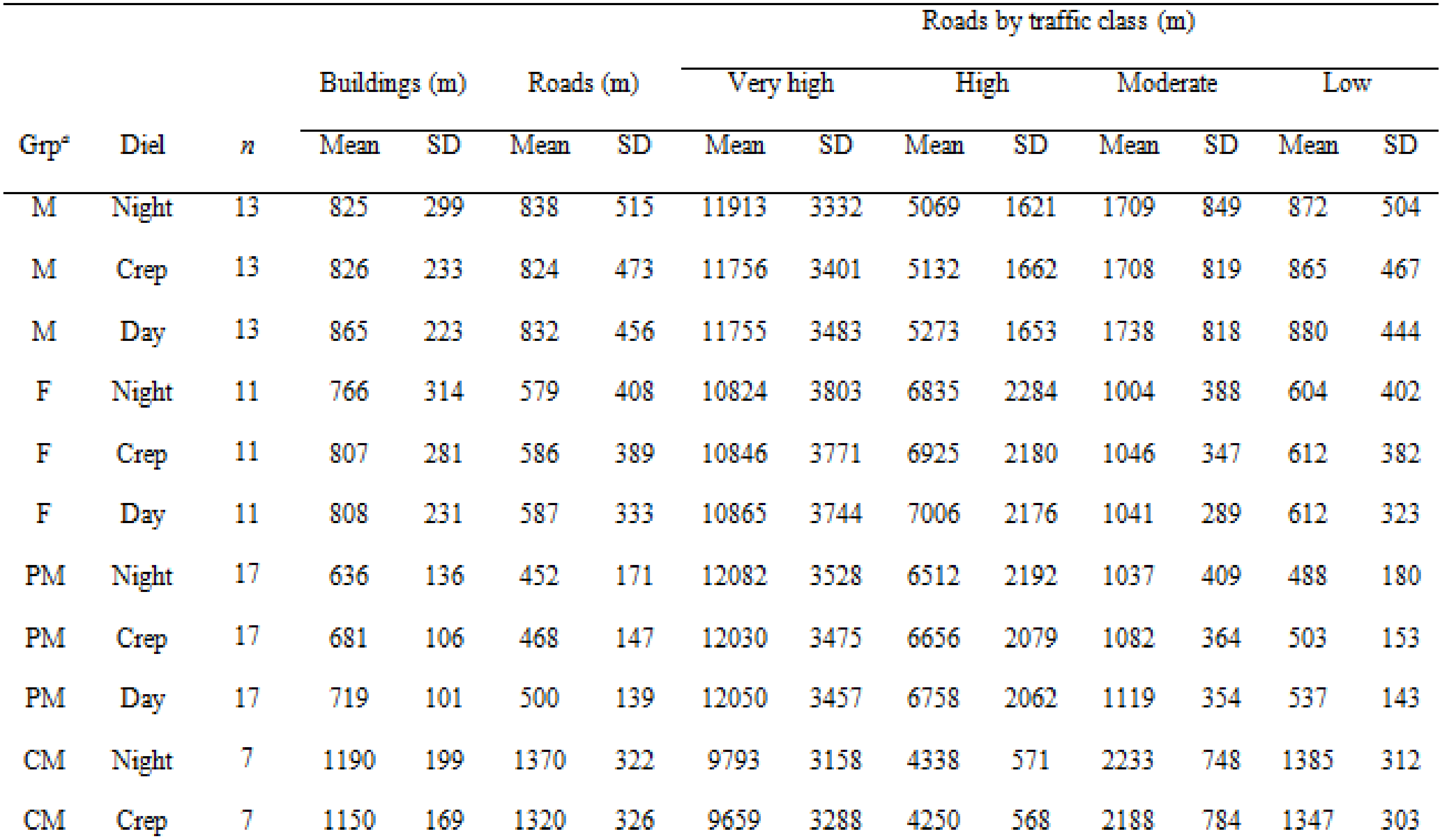
85	M	PM	0.03	0	0	0	0.03
86	M	PM	1.80	0	0	0	1.80
87	M	CM	0.04	0	0	0	0.04
91	M	PM	0.20	0	0	0	0.20
93	F	PM	1.34	0	0	0	1.34
94	M	CM	0	0	0	0	0

[a] PM=Pine Mountain, CM=Cumberland Mountain

Table 4.4. Group mean road densities within 50% fixed kernel core use areas of black bears in southeastern Kentucky, 2005-08.

		Rd. density (km/km^2)		Rd. density by traffic class (km/km^2)							
				Very high		High		Moderate		Low	
Grp[a]	N	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
M	13	0.50	0.76	0	0	0	0	0.11	0.31	0.31	0.59
F	11	0.23	0.44	0.02	0.05	0	0	0	0	0.22	0.43
PM	17	0.53	0.70	0.01	0.04	0	0	0.09	0.28	0.38	0.58
CM	7	0.007	0.02	0	0	0	0	0	0	0.007	0.02
All	24	0.38	0.64	0.007	0.04	0	0	0.06	0.23	0.27	0.51

Table 4.5. Euclidean distance of black bear locations to buildings and roads in southeastern Kentucky, 2005-08.



							Roads by traffic class (m)							
			Buildings (m)		Roads (m)		Very high		High		Moderate		Low	
Grp^a	Diel	*n*	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
M	Night	13	825	299	838	515	11913	3332	5069	1621	1709	849	872	504
M	Crep	13	826	233	824	473	11756	3401	5132	1662	1708	819	865	467
M	Day	13	865	223	832	456	11755	3483	5273	1653	1738	818	880	444
F	Night	11	766	314	579	408	10824	3803	6835	2284	1004	388	604	402
F	Crep	11	807	281	586	389	10846	3771	6925	2180	1046	347	612	382
F	Day	11	808	231	587	333	10865	3744	7006	2176	1041	289	612	323
PM	Night	17	636	136	452	171	12082	3528	6512	2192	1037	409	488	180
PM	Crep	17	681	106	468	147	12030	3475	6656	2079	1082	364	503	153
PM	Day	17	719	101	500	139	12050	3457	6758	2062	1119	354	537	143
CM	Night	7	1190	199	1370	322	9793	3158	4338	571	2233	748	1385	312
CM	Crep	7	1150	169	1320	326	9659	3288	4250	568	2188	784	1347	303

Table 4.5 (continued).

CM	Day	7	1130	160	1250	372	9639	3427	4389	603	2146	869	1291	340
All	Night	24	798	300	719	478	11414	3520	5878	2109	1386	756	749	471
All	Crep	24	818	250	715	444	11339	3526	5954	2083	1405	718	749	440
All	Day	24	839	224	720	415	11368	3554	6067	2064	1419	715	757	409

[a] M=male, F=female, PM=Pine Mountain, CM=Cumberland Mountain

Table 4.6. Group mean Euclidean distance of black bear locations to buildings and roads in southeastern Kentucky, 2005-08.

						Roads by traffic class (m)							
		Buildings (m)		Roads (m)		Very high		High		Moderate		Low	
Grp[a]	*n*	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
M	13	840	243	833	476	11800	3400	5160	1640	1720	824	874	467
F	11	794	272	583	374	10800	3770	6920	2210	1030	337	608	366
PM	17	679	108	473	146	12100	3480	6640	2110	1080	373	509	152
CM	7	1160	151	1320	324	9690	3280	4320	571	2190	793	1340	305
All	24	819	252	719	442	11400	3530	5970	2080	1400	726	752	436

[a] M=male, F=female, PM=Pine Mountain, CM=Cumberland Mountain

Table 4.7. Results of paired t-tests of Euclidean distance of used and available black bear locations to buildings and roads in southeastern Kentucky, 2005-08. Only significant values (<0.05) are presented.

							Roads by traffic class					
			Buildings		Roads		High		Moderate		Low	
Grp	Diel	*n*	*T*	*P*	*t*	*P*	*t*	*P*	*t*	*P*	*t*	*P*
M	Night	13	--	--	--	--	--	--	--	--	--	--
M	Crep	13	2.83	0.02	2.20	0.048	--	--	--	--	--	--
M	Day	13	4.59	0.0006	2.74	0.02	--	--	--	--	2.73	0.02
F	Night	11	--	--	--	--	--	--	--	--	--	--
F	Crep	11	3.31	0.008	--	--	--	--	--	--	--	--
F	Day	11	3.14	0.01	--	--	--	--	--	--	--	--
PM	Night	17			--	--	--	--	--	--	--	--
PM	Crep	17	3.24	0.0005	--	--	--	--	--	--	--	--
PM	Day	17	4.79	0.0002	--	--	--	--	--	--	--	--
CM	Night	7			3.25	0.02	--	--	--	--	--	--

Table 4.7 (continued).

CM	Crep	7	2.53	0.45	4.00	0.007	--	--	--	--	--	--
CM	Day	7	2.60	0.04	3.15	0.02	--	--	--	--	--	--
All	Night	24	2.49	0.02	--	--	--	--	--	--	--	--
All	Crep	24	3.97	0.0006	--	--	--	--	--	--	--	--
All	Day	24	5.32	<0.0001	2.34	0.03	--	--	--	--	2.09	0.048

Table 4.8. Road crossing events by black bear used in road crossing analysis, southeastern Kentucky, 2005-08.

		Crossing	Crossing events by traffic class			
ID	Sex	events	Very high	High	Moderate	Low
1	F	107	0	2	32	73
3	F	388	6	0	56	326
4	M	141	0	0	27	114
5	F	36	0	0	14	22
12	M	91	0	0	17	74
28	M	214	0	0	59	155
37	F	308	0	0	54	254
39	F	42	0	0	3	39
57	M	336	0	0	41	295
61	M	572	1	3	135	433
68	F	238	0	0	14	224
70	M	192	0	0	6	186
71	F	77	0	0	0	77
82	F	124	0	0	31	93
83	M	298	2	7	75	214
85	M	337	0	0	38	299
86	M	506	0	0	76	430
91	M	320	1	5	74	240

Table 4.8 (continued).

93	F	355	0	0	96	259

[a] Road crossing events defined as intersection of roads layer and bear movement path segments ≤4 hours in duration.

Table 4.9. Univariate comparisons of factors associated with black bear road crossings at used and available locations, southeastern Kentucky, 2005-08. Only significant values (<0.05) are presented.

Variable		Male (*n* = 10)		Female (*n* = 9)		Pooled (*n* = 19)	
		Statistic	*P*	Statistic	*P*	Statistic	*P*
Traffic class		χ^2 = 75.83	<0.0001	χ^2 = 91.66	<0.0001	χ^2 = 160.53	<0.0001
--Very high		--	--	--	--	--	--
--High		--	--	--	--	--	--
--Moderate		*S* = -19.5	0.049	--	--	*S* = -65.5	0.003
--Low		*S* = 21.5	0.0005	*S* = 15	0.04	*S* = 69.5	0.001
Distance							
--Forest		--	--	*t* = -2.34	0.048	*t* = -2.67	0.02
--Buildings		*t* = 5.35	0.0005	*t* = 4.42	0.02	*t* = 6.98	<0.0001
Elevation		*t* = 5.33	0.0005	*t* = 3.70	0.006	*t* = 6.46	<0.0001
Slope	100m	--	--	*t* = 2.55	0.03	*t* = 2.72	0.01
	500m	--	--	*t* = 2.74	0.03	--	--
	1km	--	--	--	--	--	--
Terrain Ruggedness	100m	--	--	--	--	--	--
	500m	--	--	--	--	--	--
	1km	--	--	*t* = -4.01	0.004	--	--
Sinuosity	100m	--	--	--	--	*t* = 2.29	0.03
	500m	--	--	--	--	--	--

Table 4.9 (continued).

<u>Land Cover</u>

Open	100m	*S* = -27.5	0.002	*S* = -17.5	0.004	*S* = -87	<0.0001
	500m	*S* = -26.5	0.004	*S* = -22.5	0.004	*S* = -93	<0.0001
	1km	*S* = -26.5	0.004	*S* = -17.5	0.004	*S* = -85	0.0002
Developed	100m	--	--	--	--	*S* = -55	0.03
	500m	--	--	--	--	*S* = -56	0.02
	1km	--	--	--	--	*S* = -57	0.02
Forest	100m	*S* = 26.5	0.004	*S* = 18.5	0.03	*S* =85	0.0002
	500m	*S* = 26.5	0.004	*S* = 20.5	0.01	*S* = 85	0.0002
	1km	*S* = 23.5	0.01	*S* = 17.5	0.04	*S* = 77	0.001
Agricultural	100m	*S* = -24.5	0.01	--	--	*S* = -62	0.01
	500m	*S* = -26,5	0.004	--	--	*S* = -82	0.0003
	1km	*S* = 24.5	0.001	--	--	*S* = -75	0.001
Water / Wetlands	100m	*S* = 17.5	0.04	--	--	--	--
	500m	*S* = 21.5	0.03	--	--	*S* = 60	0.01
	1km	--	--	--	--	*S* = 58	0.02

Table 4.10. Summary of black bear roadkill events in eastern Kentucky, 1993-2008.

Date	ID[a]	Sex[b]	Age[c]	County	Road	Traffic class
06/09/93		M	S	Lawrence	US-23	High
06/09/96		M	U	Lawrence	KY-645	Moderate
06/21/96		M	Y	Pike	US-23	Very high
07/28/96		M	S	Harlan	KY-522	Moderate
07/13/98		M	S	Laurel	KY-805	High
03/28/00		M	A	Floyd	US-23	Very high
08/30/00		M	A	Clay	KY-80	High
12/25/00		M	S	Harlan	KY-221	Moderate
05/09/01		M	S	Boyd	KY-773	Low
05/25/01		U	S	Lawrence	US-23	High
06/11/01		U	U	Floyd	KY-680	Moderate
05/27/03	23	M	A	Pike	US-460	Low
10/22/04		M	S	McCreary	US-27	High
05/26/05		M	S	Pike	KY-632	Moderate
12/12/05	41	M	S	Pulaski	KY-461	High
06/09/06		M	U	Perry	KY-80	High
07/07/06		U	U	McCreary	US-27	Moderate
08/03/06		M	S	Clark	KY-15	Very high
11/20/06		M	A	Lawrence	US-23	High
12/12/06		M	A	Pike	KY-805	Moderate

Table 4.10 (continued).

12/24/06		M	A	Rowan	KY-519	Moderate
06/03/07	55	M	A	Bell	US-25E	Very high
07/16/07		U	U	Lawrence	KY-3	Low
08/18/07	62	M	A	Pike	US-23	Very high
10/11/07		M	Y	Harlan	US-119	Moderate
12/07/07		M	A	Letcher	US-23	High
08/07/08		F	S	Letcher	US-23	High

[a] UK ID for bears previously captured.

[b] M=male, F=female, U=unknown

[c] A=adult, S=subadult, Y=yearling, U=unknown

Table 4.11. Univariate comparisons of factors associated with black bear roadkills at used and available locations in eastern Kentucky, 1993-2008. Only significant values (<0.05) are presented.

Variable	Buffer scale	Statistic	*P*
Traffic class	N/A	$\chi^2_3 = 76.7$	<0.0001
Distance			
--Forest	N/A	--	--
--Buildings	N/A	--	--
Elevation	N/A	--	--
Slope	100 m	$t_{25} = 2.35$	0.03
	500 m	--	--
	1 km	--	--
Terrain ruggedness	100 m	--	--
	500 m	--	--
	1 km	--	--
Sinuosity[a]			
--Very high	100 m	--	--
	500 m	$t_4 = -7.31$	0.002
--High	100 m	$t_9 = -7.52$	<0.0001
	500 m	--	--
--Moderate	100 m	$t_8 = -3.54$	0.008
	500 m	$t_8 = -3.46$	0.009

Table 4.11 (continued).

--Low	100 m	--	--
	500 m	--	--
--Pooled	100 m	--	--
	500 m	$t_{18} = -4.61$	<0.0001
Land cover			
--Open	100 m	--	--
	500 m	--	--
	1 km	--	--
--Developed	100 m	$S_{26} = 110$	0.006
	500 m	--	--
	1 km	--	--
--Forest	100 m	$S_{26} = -128$	0.0009
	500 m	--	--
	1 km	--	--
--Agricultural	100 m	--	--
	500 m	$S_{26} = -87$	0.03
	1 km	--	--
--Water/Wetlands	100 m	--	--
	500 m	$S_{26} = -118$	0.003
	1 km	$S_{26} = -83$	0.04

[a] Results for sinuosity are given separately for each traffic class.

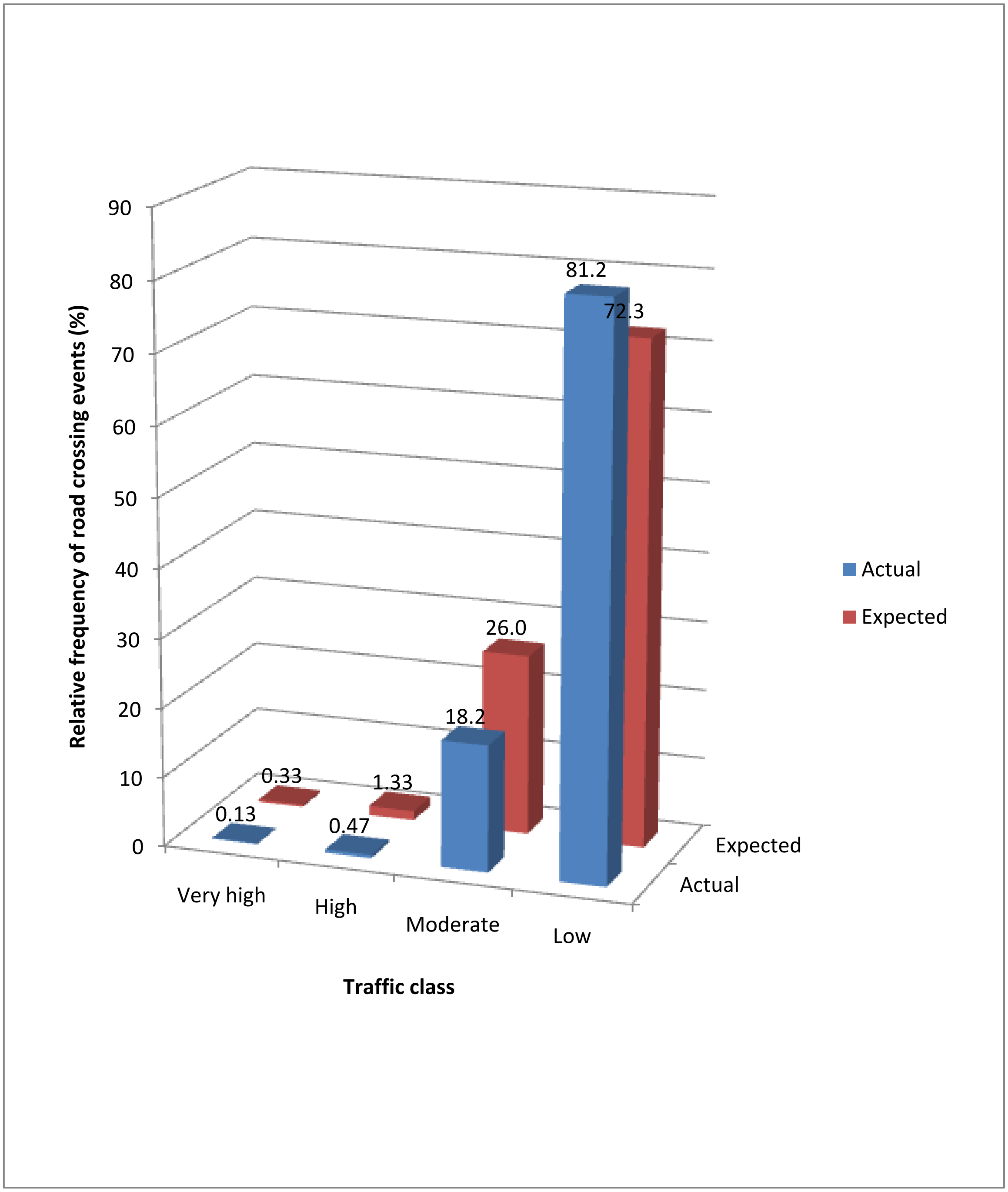


Figure 4.1. Actual and expected frequencies of male black bear road crossing events in each of the 4 traffic classes.

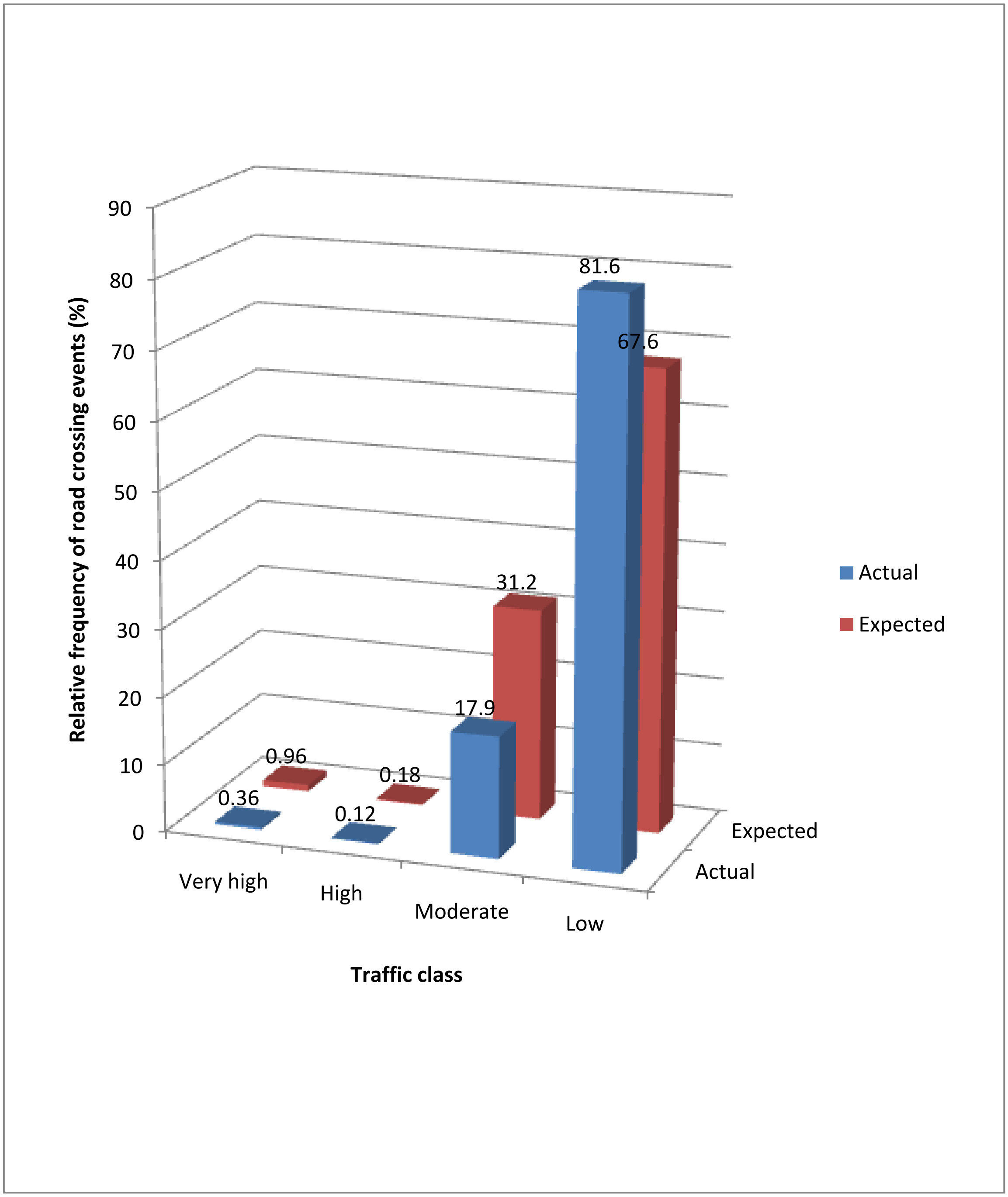


Figure 4.2. Actual and expected frequencies of female black bear road crossing events in each of the 4 traffic classes.

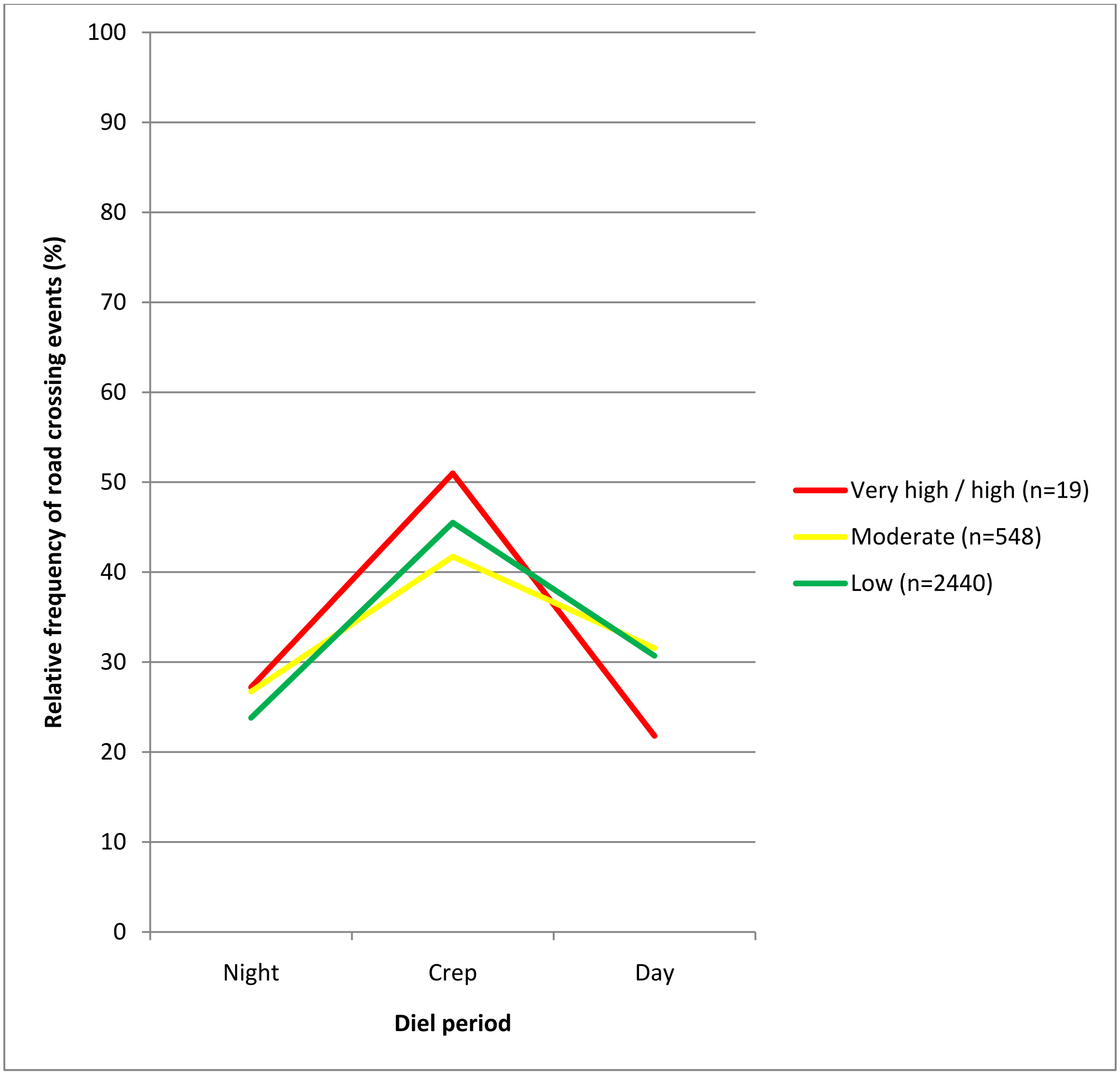


Figure 4.3. Relative frequencies of male black bear crossings of each road type in each diel period. Very high and high traffic roads were combined due to low sample size, and crossing frequencies were weighted to reflect each diel period's contribution to the 24-hour clock.

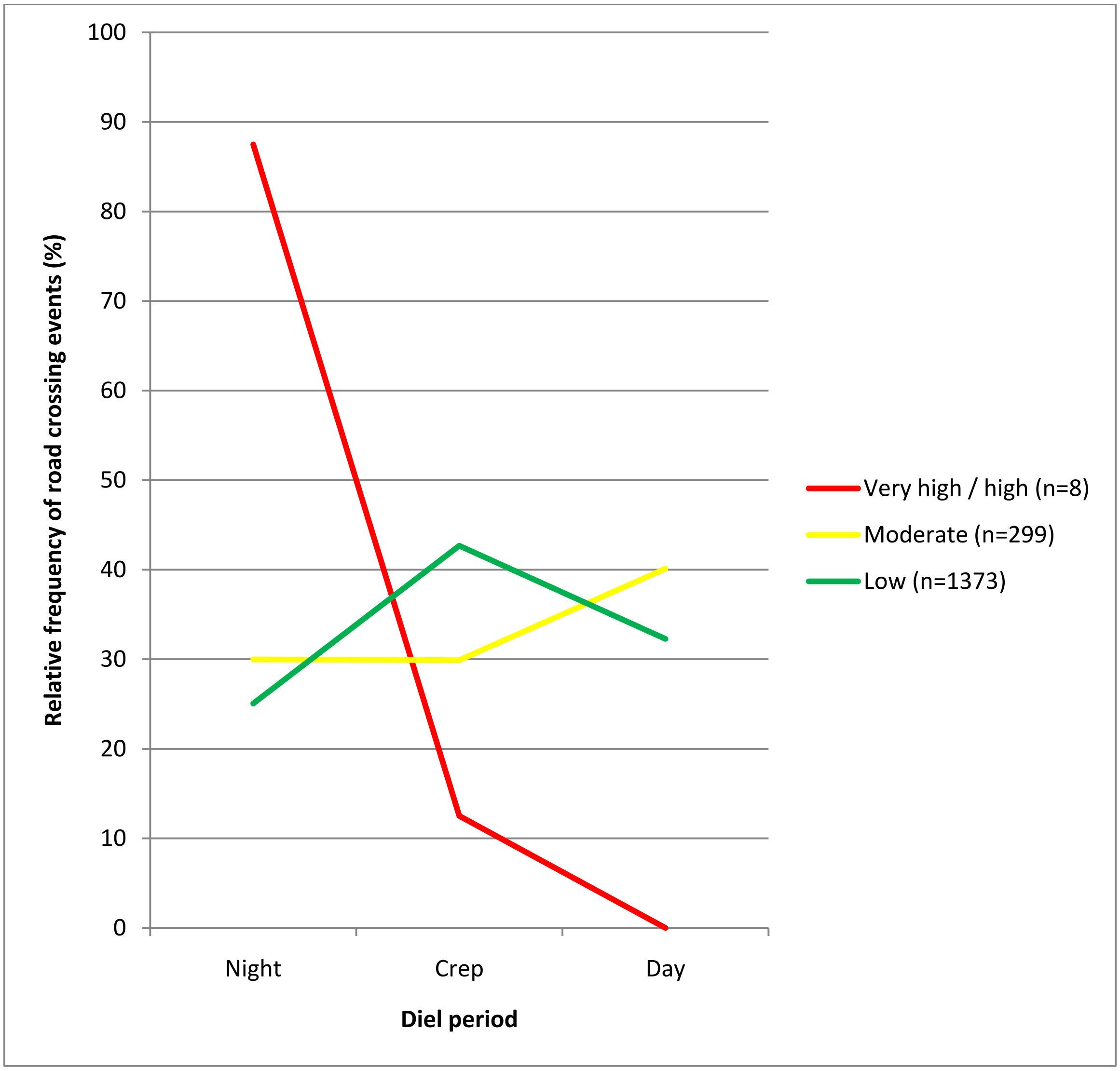


Figure 4.4. Relative frequencies of female black bear crossings of each road type in each diel period. Very high and high traffic roads were combined due to low sample size, and crossing frequencies were weighted to reflect each diel period's contribution to the 24-hour clock.

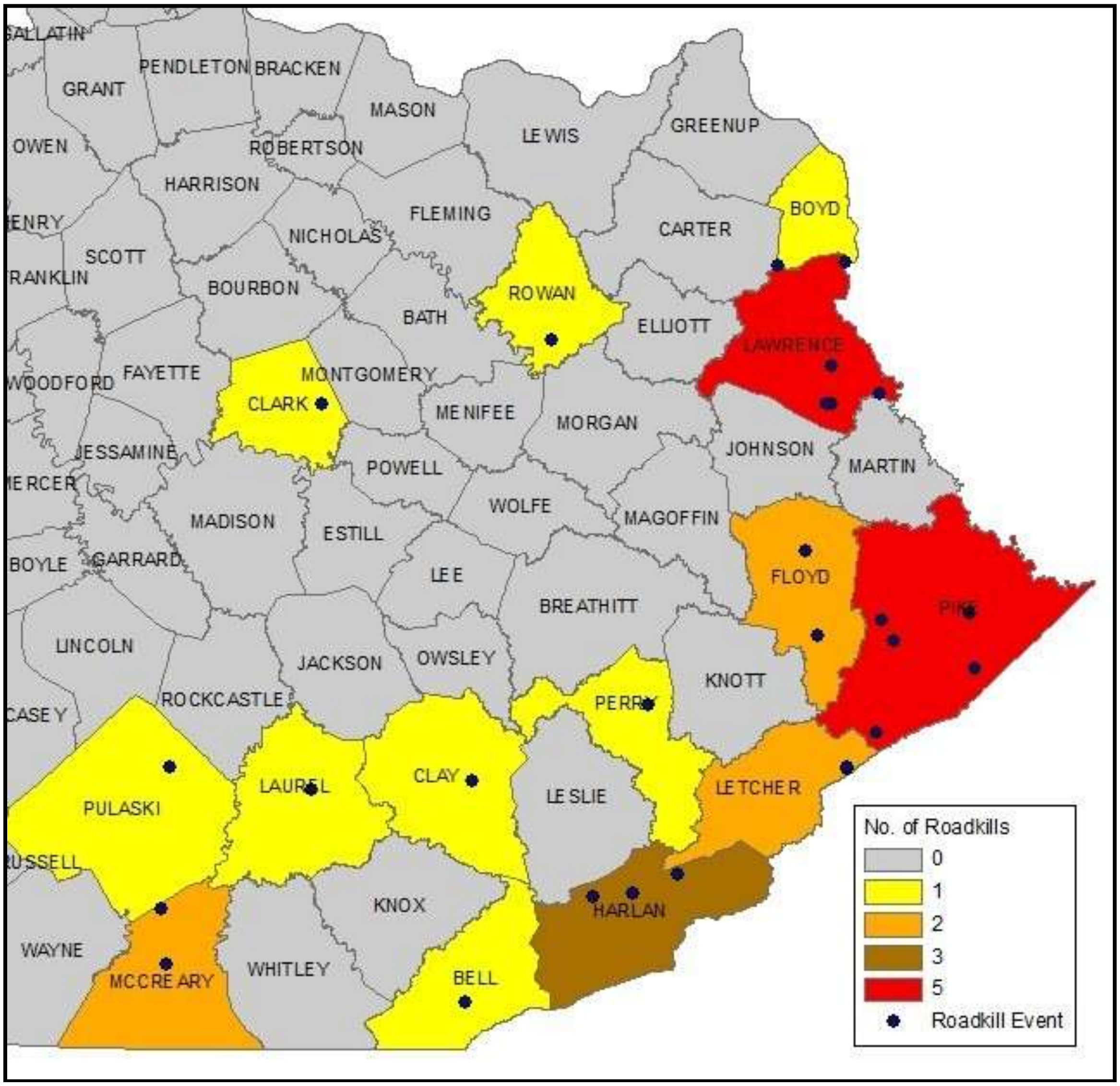


Figure 4.5. Distribution of black bear roadkills by Kentucky county, 1993-2008.

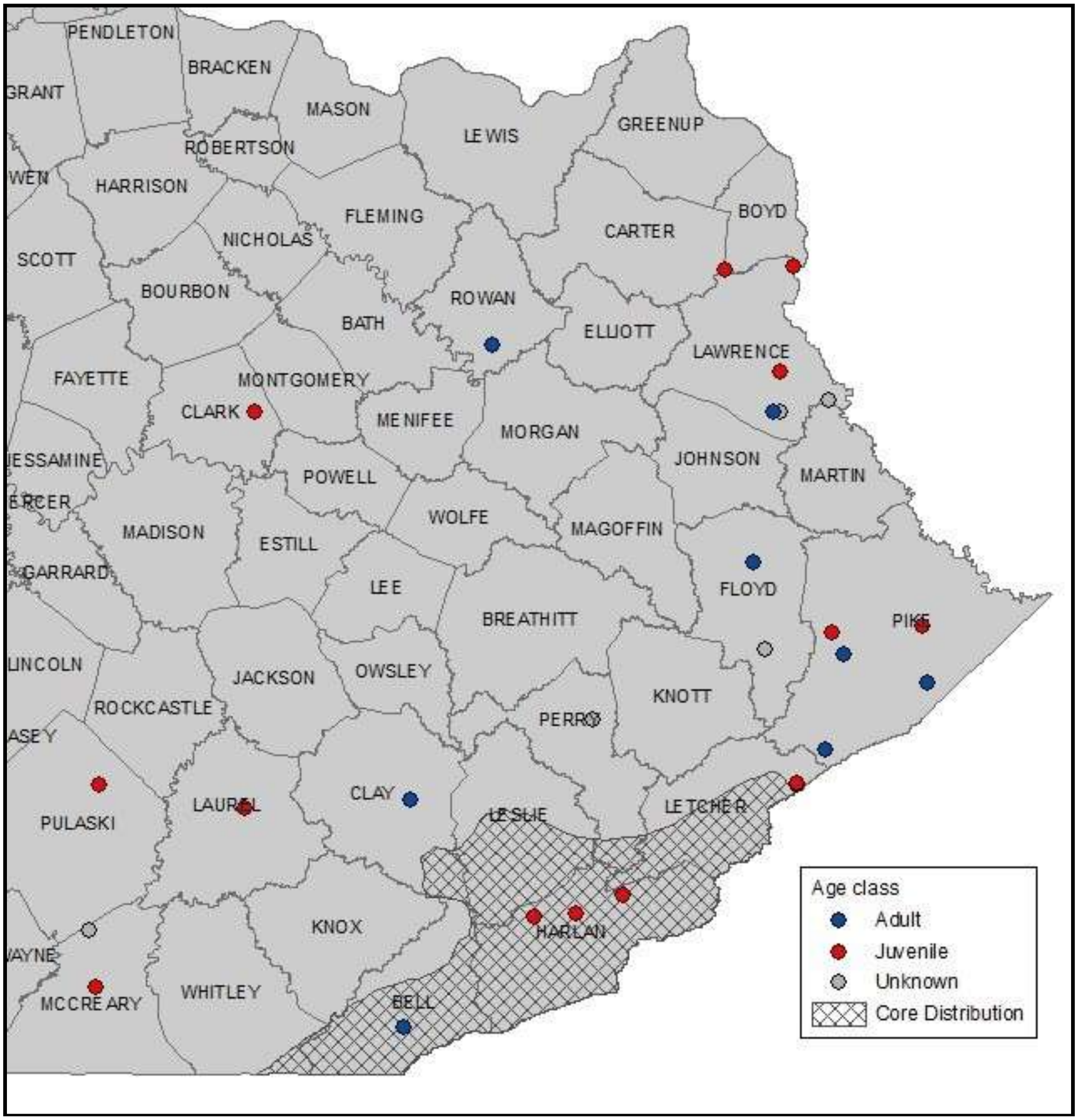


Figure 4.6. Distribution of roadkills by age class, and relative to core area of black bear distribution in Kentucky adopted from Frary (2008).

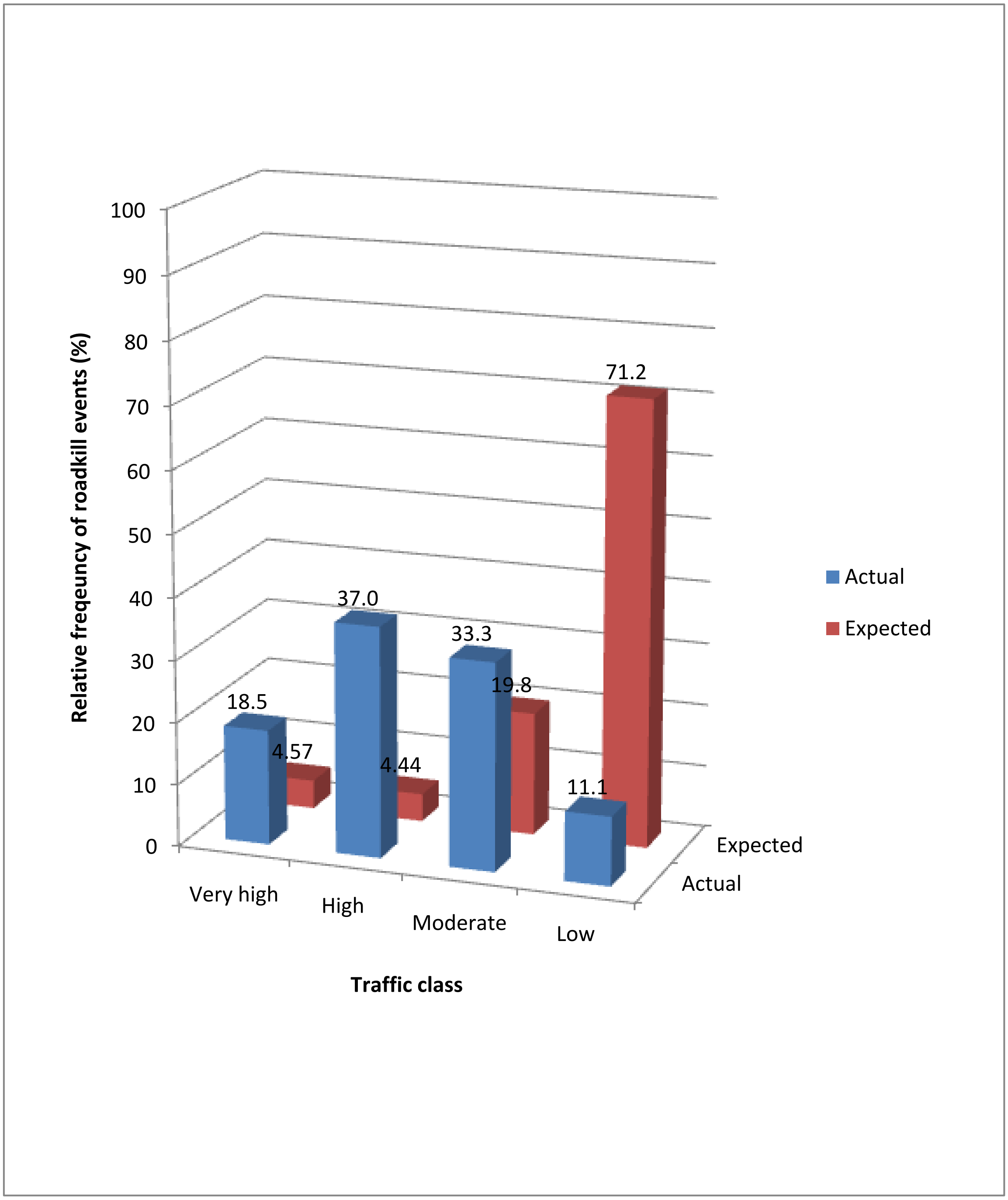


Figure 4.7. Actual and expected frequencies of black bear roadkill events in each of the 4 traffic classes.

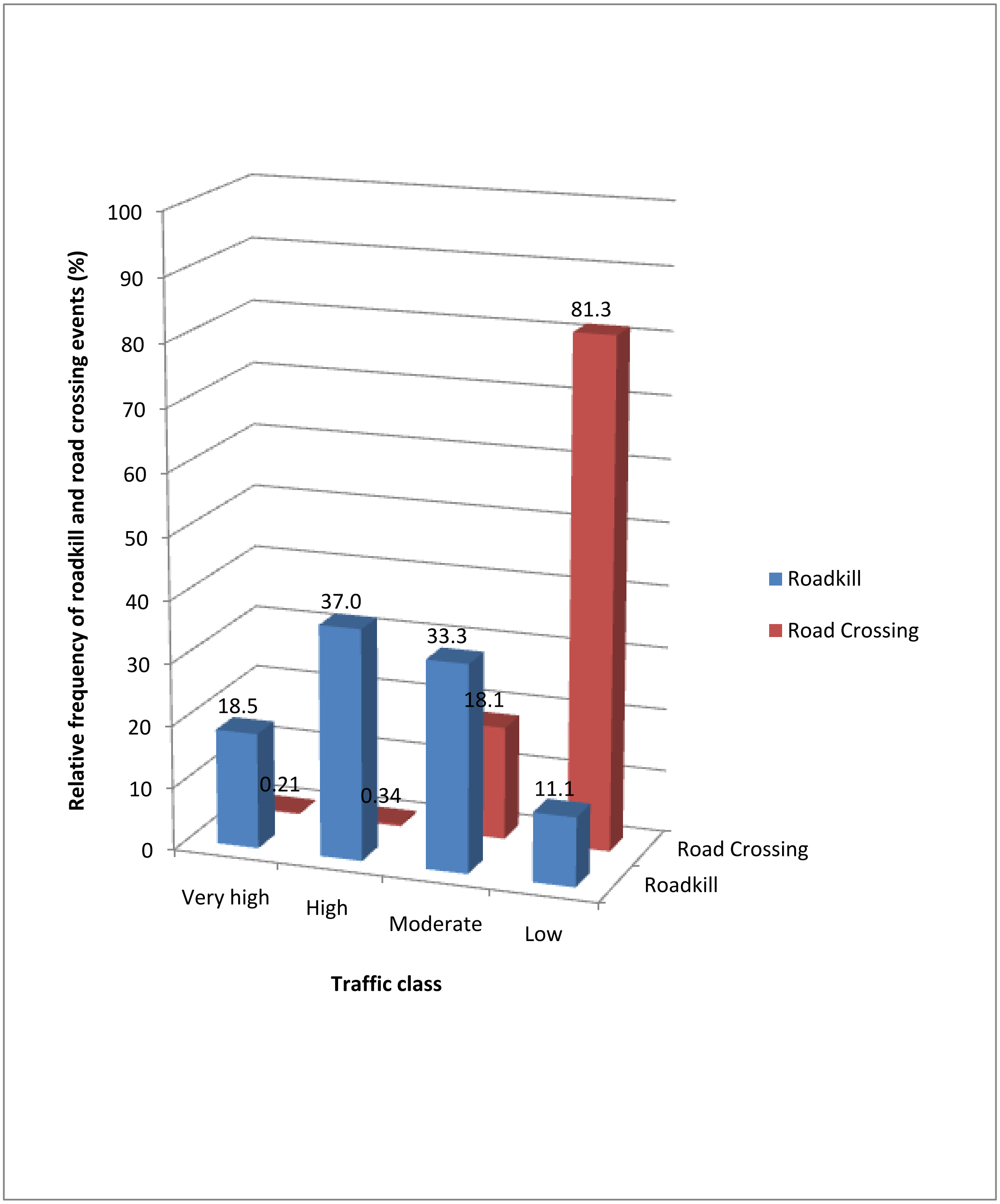


Figure 4.8. Relative frequencies of black bear roadkill and road crossing events in each of the 4 traffic classes.

CHAPTER 5

DISCUSSION

As previously shown for other black bear populations in the southeastern United States (Carr and Pelton 1984, Brody and Pelton 1989, Beringer et al. 1990, Clark et al. 1993, Fecske et al. 2002, Maehr et al. 2003, Orlando 2003, Reynolds-Hogland and Mitchell 2007), space use and movements of the black bear in eastern Kentucky appear to be influenced by roads. Bears in this study were vulnerable to collisions with vehicles, with higher roadkill rates observed for those demographic groups predisposed to lengthy dispersal movements. Bears also displayed road avoidance via non-random space use relative to roads and reduced permeability of certain roads or sections of roads. Road avoidance patterns reflected costs and benefits associated with road crossing and use of habitats near roads, and varied along gender and regional lines. Road-mediated restriction of movements at both the home range and landscape scale constituted an "early warning" symptom of the barrier effect.

Bears in this study exhibited second-order road avoidance by occupying home ranges with road densities lower than the surrounding landscape. These trends were more pronounced among Cumberland Mountain bears than Pine Mountain bears, among males than females, and among females caring for cubs of the year than females traveling with yearling cubs. However, all groups except for females with yearling cubs occupied home ranges with densities of at least one traffic class lower than expected, and no group occupied a home range with densities of any traffic class higher than expected. At the level of the 50% core area, roads appeared to exert an even stronger negative effect. All groups except Cumberland Mountain bears had lower road densities in their core areas than in their 95% home ranges, and the core areas of 13 (54.2%) of 24 bears contained no roads at all. Even F001, the bear with the highest 95% home range total road density observed in this study at 2.36 km/km^2, had a 50% core area that was roadless.

Second-order road avoidance varied by traffic class. High traffic roads were the most frequently avoided, with bears of both genders and regions including these roads at lower densities than expected in their home ranges and core areas. Interestingly, low traffic roads were the second most frequently avoided, with lower densities than expected in the home ranges of males and Cumberland Mountain bears, and in the core areas of both genders and regions. The importance of low traffic roads in second-order road avoidance was likely due to their ubiquity; low traffic roads comprised 76.8% of the study area road network, so areas of lower total road density selected by bears were usually, by default, areas of lower density of low traffic roads. Avoidance patterns by traffic class were perhaps more accurately described by analysis of road network composition. High and high traffic roads generally comprised a lower proportion of home range and core area road networks than in the surrounding landscape, while moderate and low traffic roads accounted for a proportion of home range and core area road networks approximating random. However, females caring for cubs of the year occupied home ranges with lower relative frequencies of moderate traffic roads and higher relative frequencies of low traffic roads than males. Differential second-order road avoidance by traffic volume has previously been documented in the bobcat (Lovallo and Anderson 1996) and grizzly bear (Mace et al. 1996).

Males in the present study had 95% home range total road densities that averaged 0.73 km/km^2, and females 0.84 km/km^2. These values were similar to those obtained by Fecske et al. (2002) for black bears in western Maryland, but were slightly lower than those obtained by Brody and Pelton (1989) for black bears in Harmon Den, North Carolina. The latter population occupied home ranges with average unrestricted road densities of 1.01-1.38 km/km^2, depending on gender and season. This discrepancy can be explained in two ways. First, all roads included in Brody and Pelton (1989)'s road density analyses were unpaved and of relatively low traffic volume, while the majority of roads in the present study were paved, with traffic volumes ranging from 7-25,392 vehicles/day. Previous work has shown that black bears are more likely to avoid roads of higher traffic volume (Beringer et al. 1990, Orlando 2003) and generally avoid paved roads (Fecske et al. 2002). Conversely, bears may use unpaved roads as travel corridors (Hellgren 1991). Hence, higher road densities among Harmon Den bears might reflect the lower-risk or advantageous nature of these roads, relative to the road network of the present study. Secondly, Brody and Pelton (1989) calculated home ranges using the 100% MCP method, while I used 95% fixed kernels. Because 95% kernels do not depict all of a bear's space use, associated road densities may not reflect road-dense areas visited occasionally by bears.

In the present study, mean total road density of the 95% kernels of all bears pooled was 0.78 km/km^2, a value that exceeded the 0.6 km/km^2 threshold given for a naturally functioning landscape containing sustained populations of large mammals (Forman and Hersperger 1996). Previous studies of the mountain lion and grizzly bear obtained average home range road density levels of 0.6 km/km^2 and 0.61 km/km^2, respectively (van Dyke et al. 1986, Mace et al. 1996), and wolves have been found to be absent when road densities exceed this level (Mech 1988). In Kentucky, significant differences in road densities were observed by region, with total road densities of Pine Mountain 95% kernels averaging 1.01 km/km^2, compared to 0.11 km/km^2 for Cumberland Mountain. Possibly, bears of the different regions of the study area have different road density thresholds linked to resource utilization. Pine Mountain bears appear to be more reliant on anthropogenic food than Cumberland Mountain bears (pers. obs.), and may not be as negatively impacted by higher road densities.

Bears in this study exhibited third-order road avoidance by using habitats farther from roads than what was expected based on within-home-range availability. As with second-order road avoidance, third-order road avoidance was more pronounced among Cumberland Mountain bears than Pine Mountain bears, and among males than females. However, females and Pine Mountain bears afforded a greater distance to high traffic roads than males and Cumberland Mountain bears, respectively. Females and Pine Mountain bears shifted space use with respect to roads by time of day, with females moving closer to high traffic roads, and Pine Mountain bears all traffic classes, during crepuscular and nighttime hours. Similarly, males did not appear to avoid roads at night. McLellan and Shackleton (1988) attributed nighttime use of habitats near roads by grizzly bears to behavioral reduction of habitat loss, in which areas that would otherwise have been unavailable due to the potential for negative encounters with humans were utilized only during hours of low risk. Likely, nighttime use of habitats near roads by black bears in eastern Kentucky was driven in part by this population’s reliance on anthropogenic food, a theory supported by my observation that, while bears of both genders and regions avoided buildings by day, no group avoided buildings at night.

That Pine Mountain bears did not exhibit second- or third-order avoidance of the overall road network was not surprising, as 9 (52.9%) of 17 animals had nuisance track records (KDFWR, unpublished data) and were known to utilize anthropogenic food that was plentiful near roads. However, lack of second- or third-order road avoidance for females at the level of the 95% home range was unexpected. Only 2 (18.2%) of the 11 females included in the road avoidance analyses had documented nuisance behavior (KDFWR, unpublished data). The picture is further complicated by the fact that males, consistent avoiders of roads in this study, were also consistent nuisance offenders, with 7 (53.8%) of 13 having been captured or hazed as a result of nuisance behavior (KDFWR, unpublished data). Possibly, an influence other than utilization of anthropogenic food is responsible for patterns of non-avoidance in female Kentucky black bears. Female black bears in the Great Dismal Swamp of Virginia were found significantly closer to roads than expected, perhaps due to utilization of early successional vegetation or use of roads as travel corridors (Hellgren et al. 1991). Female grizzly bears in British Columbia used areas near roads significantly more than males, possibly because the risk of encountering males was lower in these suboptimal habitats (McLellan and Shackleton 1988).

Bears in this study also exhibited a form of road avoidance by crossing roads in areas or at times of day that minimized risk. Risk of vehicle-caused mortality increases with traffic volume (Jaeger et al. 2005); accordingly, low traffic roads in the present study accounted for a higher proportion of crossing events than expected, and moderate traffic roads a lower proportion. This suggests that, for bears in eastern Kentucky, risks associated with road crossing begin to outweigh benefits above a threshold of 600 ADT. Interestingly, the trend of higher-than-expected crossing of low traffic roads and lower-than-expected crossing of moderate traffic roads was observed in males and females with yearling cubs, but not in females with cubs of the year. However, females with cubs of the year had an average daily crossing rate 13.4% lower than females with yearling cubs, and were never observed to cross very high or high traffic roads.

In addition to avoiding crossing higher traffic roads, bears can reduce road mortality risk by crossing at times of day when traffic is lower (McLellan and Shackleton 1988, Chruszcz et al. 2003, Waller and Servheen 2005, Graves et al. 2006). Bears in the present study were most likely to cross roads during the crepuscular period, and least likely to cross at night. This seems counterintuitive, as traffic should have been highest during the crepuscular period due to the morning and evening commute, and lowest at night. However, 81.3% of crossing events were of low traffic roads, which might not have presented enough of a road mortality risk to warrant a switch to nighttime crossing. Further, low traffic roads might not have experienced temporal fluctuations in traffic levels sufficient to elicit a behavioral response from black bears. Notably, there was an increasing trend of nighttime crossing for roads of the higher traffic classes.

Females in the present study crossed roads at locations closer to forest than expected, a finding similar to Chruszcz et al. (2003), who observed a tendency for grizzly bears to cross roads in areas of dense vegetation. Chruszcz et al. (2003) suggested that cover might be a requirement for providing security from road-related disturbance. Bears in this study crossed roads at locations further from buildings than expected, perhaps affording themselves further insurance against detection by humans. Further, bears crossed farther from buildings by day than at night. This pattern can be viewed as resulting from both road-related risks and benefits. First, bears face the risk of human detection during daytime crossing, and shift crossing locations away from developed areas to minimize this risk. Second, many bears enjoy the benefit of anthropogenic food during hours of low human activity, and cross roads closer to human use areas at night in order to avail themselves of this resource. Nine (47.4%) of 19 bears used for the road crossing analysis had track records of nuisance behavior, including foraging in dumpsters, knocking over trash cans, and eating pet food from residents' porches (J. Hast, UK, pers. comm.). Just as space use elsewhere in the home range reflects use of wild foods, space use in developed areas reflects use of anthropogenic resources, obtained in such a way as to maximize a bear's chance of survival.

The tendency of Kentucky black bears to cross roads at higher elevations than expected was likely a reflection of third-order habitat selection by bears of this population rather than selection of road crossing locations that optimally balance costs and benefits. Kentucky black bears were shown previously to prefer the steep slopes and ridgetops of Pine Mountain (Unger 2008). Elsewhere, grizzly bears have been found to migrate to lower elevations seasonally for use of riparian vegetation, but such movements may be halted by heavy anthropogenic presence at lower elevations (McLellan and Hovey 2001). In the present study, females crossed roads at higher elevations than males, likely due to differences in second-order selection between the genders. Such differences may have resulted from differential use of resources in the study area, or could be mediated by mutual exclusion of the genders in space (McLellan and Shackleton 1988). Differential use of space along an elevational gradient was observed in male and female grizzly bears, with males using productive habitats at lower elevations, and females restricted to higher sites (Zager 1980).

At smaller scales of analysis, females crossed roads where slopes were steeper than expected. Second-order selection of moderately sloping terrain has been documented previously for black bears (Clark et al. 1993), and Kentucky black bears were previously shown to respond to slope and other topographical parameters at the level of second-order selection by aligning their home ranges along major topographical gradients (Unger 2007). I am not aware of studies linking slope to road crossing site selection in black bears; however, black bears in North Carolina preferentially crossed roads at major drainages (Brandenburg 1996), which would likely influence mean slope values at crossing sites. At the 1-km scale of analysis, females crossed roads where terrain ruggedness was lower than expected. This was also found to be true for grizzly bear road crossing sites (Chruszcz et al. 2003) and cougar travel routes across the landscape (Dickson et al. 2005).

At all scales of analysis, bears crossed roads where forest cover was more plentiful than expected, and open and developed land less plentiful. At the 1-km scale of analysis, such preferences likely reflect third-order habitat selection rather than optimal balance of road-related costs and benefits. Bears of this population were previously found to use habitats significantly closer to mixed and deciduous forest than expected, and significantly farther from shrub-herb (open) habitats and semi-urban (developed) areas (Unger 2007). However, at smaller scales of analysis, preferentially crossing roads in areas of forest cover, and avoiding crossing roads in exposed or developed areas, may reflect minimizing risk of detection by humans.

Finally, bears crossed roads that were more sinuous than expected at the smallest scale of analysis. As with elevated slopes, increased sinuosity at road crossing sites may reflect a preference for crossing roads at drainages, as was observed by Brandenburg (1996), or where ridgelines intersect the road. Alternately, crossing roads in locations where visibility of traffic is limited may decrease a bear's perceived risk of road mortality or detection by humans. Teasing out the influence of each of these associations by including landform classification in analysis of road crossing sites represents a good direction for future research.

Interestingly, although males displayed more evidence of second- and third-order road avoidance than females, females appeared to be more reticent in terms of road crossing. Females crossed roads at a rate less than half that of males, used sites that were steeper and closer to forest cover than expected, and crossed farther from buildings than males during daylight hours. Elsewhere, females have been observed to cross roads less frequently than males (McCown et al. 2004); however, I am not aware of studies that have exposed gender differences in selection of crossing sites. Such selectivity might have reflected greater pressure on females to cross where risk of detection by humans was low. All females in this study were of reproductive age, so low road crossing rates and high site selectivity might have reflected the potential fitness gains offered those females that minimized vehicle- and human-caused mortality risks for their cubs.

Roadkills occurred primarily in juvenile males outside of the core area of black bear distribution in Kentucky adopted from Frary (2008). Although males crossed roads more frequently than females, the odds ratio I obtained for road crossing was insufficient to explain the discrepancy between male and female roadkill rates in peripheral areas. If road mortality can be considered a sampling tool, then it is reasonable to conclude that sex ratios of the Kentucky black bear are skewed toward males outside of the core area of distribution. Assuming that road crossing rates of Kentucky black bears, like those of other populations in the southeastern United States (Brody and Pelton 1989), do not differ by age, it is also reasonable to conclude that age structure in peripheral areas is skewed toward juveniles. These patterns are symptomatic of expanding carnivore populations (Swenson et al. 1998), and indicate that recolonization by the Kentucky black bear is still in progress.

However, long-distance dispersal attempts may be accompanied by increased road mortality risk, as was shown in studies of Florida's GCE black bear population, in which all bears attempting to disperse to other populations were road-killed (Gilbert and Wooding 1996, Larkin et al. 2004). Annual black bear roadkill rates in Kentucky have been generally on the rise since the first roadkill was documented in 1993 (Figure 4.1). The maximum annual roadkill tally during the period 1993-2008 was in 2006, when 7 road mortality events were documented. This rate represents 7% of the recent population estimate of 100 bears (Frary 2008). Although black bear populations elsewhere have exhibited higher annual roadkill rates (Gibeau and Heuer 1996), a 7% rate is higher than that reported for the GCE population, which has the lowest level of genetic variability of any black bear population (Dixon et al. 2007). Annual removal of this proportion of the population through collisions with vehicles could affect demographics of the Kentucky black bear, given that the population is also impacted by poaching and, effective December 2009, legal harvest.

Several variables occurred in roadkill events at levels significantly different than what was predicted by chance. These included traffic class, road sinuosity, slope, and land cover composition. Black bear roadkills occurred on a complement of road classes different than that of available locations in the roadkill study area, with most roadkills occurring on high and moderate traffic roads. At the smallest scale of analysis, roadkills occurred where roads were straighter, adjacent slopes steeper, developed land more prevalent, and forest less prevalent than expected. At the intermediate scale, roadkills occurred where roads were straighter, and agricultural land and open water and wetlands less prevalent than expected. At the largest scale, the only roadkill variable that differed from random was proportion of open water and wetlands, which was lower than expected. That roadkills were linked not so much to landscape-scale patterns (reflecting second-order selection) as to local-scale patterns (reflecting third-order selection) is consistent with the observation that most roadkills occurred outside of the core area of black bear distribution, where second-order selection may not have been operating.

Three of the variables significantly associated with roadkill sites were those I originally hypothesized to be factors in black bear road mortality risk: traffic class, road sinuosity, and local-scale land cover composition. I predicted that these variables would occur at different levels in roadkills than in successful crossing events. This was at least partly true. Black bear roadkills occurred on a different complement of road classes than road crossings, with most roadkills occurring on high and moderate traffic roads, and the vast majority of crossing events occurring on low traffic roads. When I controlled for traffic class, roadkills occurred on straighter sections of road than road crossing events.

Land cover composition did differ between roadkills and road crossings at the local scale, with forest less prevalent at roadkill sites. However, land cover composition also differed beyond the local scale, a finding I did not anticipate. Forest was less prevalent and agricultural land more prevalent at roadkill than at road crossing sites at the two larger scales of analysis. This might again be explained in terms of second-order selection. If second-order selection was not operating outside the core area of black bear distribution, it follows that large-scale land cover composition should differ between roadkill and road crossing locations, where second-order selection was occurring.

The remaining variables—distance to buildings and forest, elevation, slope, and terrain ruggedness—were hypothesized to influence bear space use and movement, but not road mortality risk. Hence, these variables were predicted to occur in roadkills at levels not significantly different from those of road crossing events. This turned out to be incorrect. Roadkills occurred farther from forest cover, and, when I controlled for regional differences, at lower elevations than road crossings. The significance of elevation is likely related to a variable not investigated in the present study: traffic speed. Previous studies have found significant correlations between road mortality incidence and vehicular speed (Dickerson 1939, Case 1978). In the Cumberland Mountains, well-traveled highways such as US-119 and US-421 have relatively low attainable speeds at high elevations, since these roads curve with the landscape and negotiate slopes using switchbacks. Thus, even controlling for traffic class, risk of being road-killed should decrease with increasing elevation. The significance of distance to forest cover may be tied to elevation, as mountain roads tend to have narrower shoulders than valley roads of similar traffic volume. Future research into road mortality patterns in this population should include vehicular speed as a potential determinate of roadkill events.

As traffic class appeared the strongest road mortality risk factor for the Kentucky black bear, it is worth further mention. Recall that very high traffic roads accounted for a relatively low proportion of roadkill events, contributing only about half of the events that either high or moderate traffic roads did. It is intuitive that very high traffic roads would account for fewer roadkill events than moderate traffic roads, as bears in this study crossed moderate traffic roads at a rate more than 25 times that of very high traffic roads. Further, moderate traffic roads were more than 4 times as abundant as very high traffic roads in random sampling of the 14-county roadkill study area. Clevenger et al. (2003) attributed the relatively low mammal roadkill rates on the busy Trans-Canada Highway to the repellent nature of a highway of this width, speed, and traffic volume. However, the finding that high traffic roads accounted for twice as many roadkills as very high traffic roads is less clear. Bears in this study crossed very high and high traffic roads at approximately equal rates. Further, very high and high traffic roads were present at approximately equal levels in the roadkill study area. Possibly, bears cross very high traffic roads more strategically than high traffic roads, increasing their chance of success in the former case. This is supported by my observation that, as traffic volume increased, bears were increasingly likely to cross roads at night.

Overall, the road avoidance and road crossing patterns of black bears in the present study are consistent with the idea that use of habitats near roads and crossing roads are the result of a tradeoff between road-related costs and benefits (Brody and Pelton 1989). The *Road Avoidance: Present* hypothesis was upheld because bears were located farther from expected than roads overall, and because crossings occurred non-randomly in space and time. The *Road Avoidance: Cost/Benefit* hypothesis was upheld because 1) bears crossed higher traffic roads at levels disproportionately lower, and lower traffic roads at levels disproportionately higher, than their occurrence in home ranges, 2) with increased traffic volume, bears shifted to nighttime crossing of roads, 3) females and Pine Mountain bears shifted space use away from roads during daylight hours, 4) as traffic volume increased, bears increased their night-to-day shift away from roads, and 5) bears crossed roads farther from buildings during the day than at night.

The *Road Mortality: Traveler* hypothesis was upheld because most roadkills occurred in males (81.5% of the total), and in subadults or yearlings (48.1% of the total). The *Road Mortality: Mechanisms* hypothesis was upheld because 1) roadkills occurred non-randomly with respect to traffic class, and local-scale slope, road sinuosity, and land cover composition, and 2) successful and unsuccessful road crossings differed with respect to traffic class and sinuosity, variables previously shown to influence road mortality risk (Bashore 1985, Clevenger et al. 2003, Jaeger et al. 2005). Several other predictions related to the *Road Mortality: Mechanisms* hypothesis were not validated, however. Successful and unsuccessful crossings differed in terms of elevation, distance to forest cover, and large-scale land cover composition, all of which were predicted to be more reflective of habitat selection than of road mortality risk. Clarification of the role of elevation and distance to forest cover in successful and unsuccessful road crossings might be achieved by including traffic speed in future modeling of roadkill locations.

Finally, the *Barrier Effect: Present* hypothesis was upheld because bears in this study 1) exhibited restricted within-home-range space use and movements in terms of higher-than-expected distance to roads and reduced permeability of roads across spatial and temporal bounds, and 2) were not able to fully utilize the available landscape, i.e. they occupied home ranges with lower road densities than expected. The barrier effect of roads upon the Kentucky black bear does not appear to be profound at this point, as bears are occasionally observed outside of the core area, and the majority of bear roadkills occurred outside this area. However, it is noteworthy that during the period 1987-2008, no female was road-killed, captured, or found dead outside of the core area, as compared to 60 males (KDFWR, unpublished data). This indicates that barriers in the landscape—including the barrier effect of roads—might be acting differentially on males and females, a notion supported by evidence of more selective road crossing by females than males in the present study. Already handicapped by low dispersal rates (Rogers 1987a) and average dispersal distances (Maehr 1997, Hellgren 2005), females might not be able to negotiate the additional pressure of the barrier effect in expanding their range beyond the current core distribution area. The region to the north and the west of the Cumberland Mountains may operate as an ecological sink, collecting male dispersers without rewarding them with breeding opportunities, and ultimately promoting their demise through road mortality or poaching.

Future Research and Management Implications

Although it does not appear that the barrier effect of roads is having a profound impact on the Kentucky black bear at this point, continued investigations are warranted. Two variables omitted from my analyses should be included in future analyses; namely, traffic speed (useful for all analyses in the present study) and topographic position of road crossing and roadkill sites. The former would be best obtained through actual measurement, but could be approximated using data already in place, such as road classification schemes used by the Kentucky Transportation Cabinet. The latter would require highly accurate estimates of road crossing locations, which might be obtained by further querying road crossing data to only those events generated from path segments ≤ 1 hr in duration. Were such a filter to be imposed on the existing dataset, 14 individuals (6F, 8M) would still be eligible for road crossing analyses.

Following univariate testing of the significance of traffic speed and topographic position in road crossing and road mortality events, multivariate testing should be undertaken for all variables significantly associated with road crossing and road mortality. These models could then be combined with a black bear probability of occupancy map (Frary 2008) to quantify the likelihood of bear road crossing and road mortality events across the Kentucky road network. A new map displaying these potential hotspots would make the results of my research more accessible to transportation planners and wildlife managers, and could aid highway mitigation efforts to facilitate landscape connectivity for the black bear, while allowing for safer travel for humans.

Additional investigations into road avoidance should identify a road-effect zone for the Kentucky black bear, similar to Forman (2000). The most straightforward way to do this would be through band analyses, in which space use is examined across graduated distance isopleths. Previous investigations have used band analyses to identify the distance over which road avoidance by bears is statistically significant (McLellan and Shackleton 1988, Kasworm and Manley 1990, Hellgren et al. 1991, Orlando 2003, Reynolds-Hogland and Mitchell 2007). Applying band analyses to the present data would place Kentucky black bear road avoidance patterns in the context of what has been revealed for other black bear populations. Further, band analyses relative to traffic class could be used to map the road-effect zone for the Kentucky black bear across their distribution in the Commonwealth. A better understanding of the road-effect zone for the Kentucky black bear would increase the accuracy of cumulative impacts assessments prior to highway construction or expansion, and might inspire mitigation for habitat loss.

At the present time, my central management recommendation pertains to public education. Black bears in eastern Kentucky, particularly those residing on or near Pine Mountain, appear to be making regular use of roadside anthropogenic foods. Such behavior increases a bear’s risk of being poached, road-killed, or removed due to safety concerns (Reynolds-Hogland and Mitchell 2007, Beckmann and Lackey 2008). Although the feeding of bears in eastern Kentucky is not always intentional, it can generally be prevented. Proper storage of garbage, pet food, bird seed, and other anthropogenic food sources should be mandated both in residential areas and at problem public sites such as Kingdom Come State Park. The expectation that bears remain on “good behavior” near populated areas is unreasonable as long as humans are participating wholesale in their habituation.

Conclusions

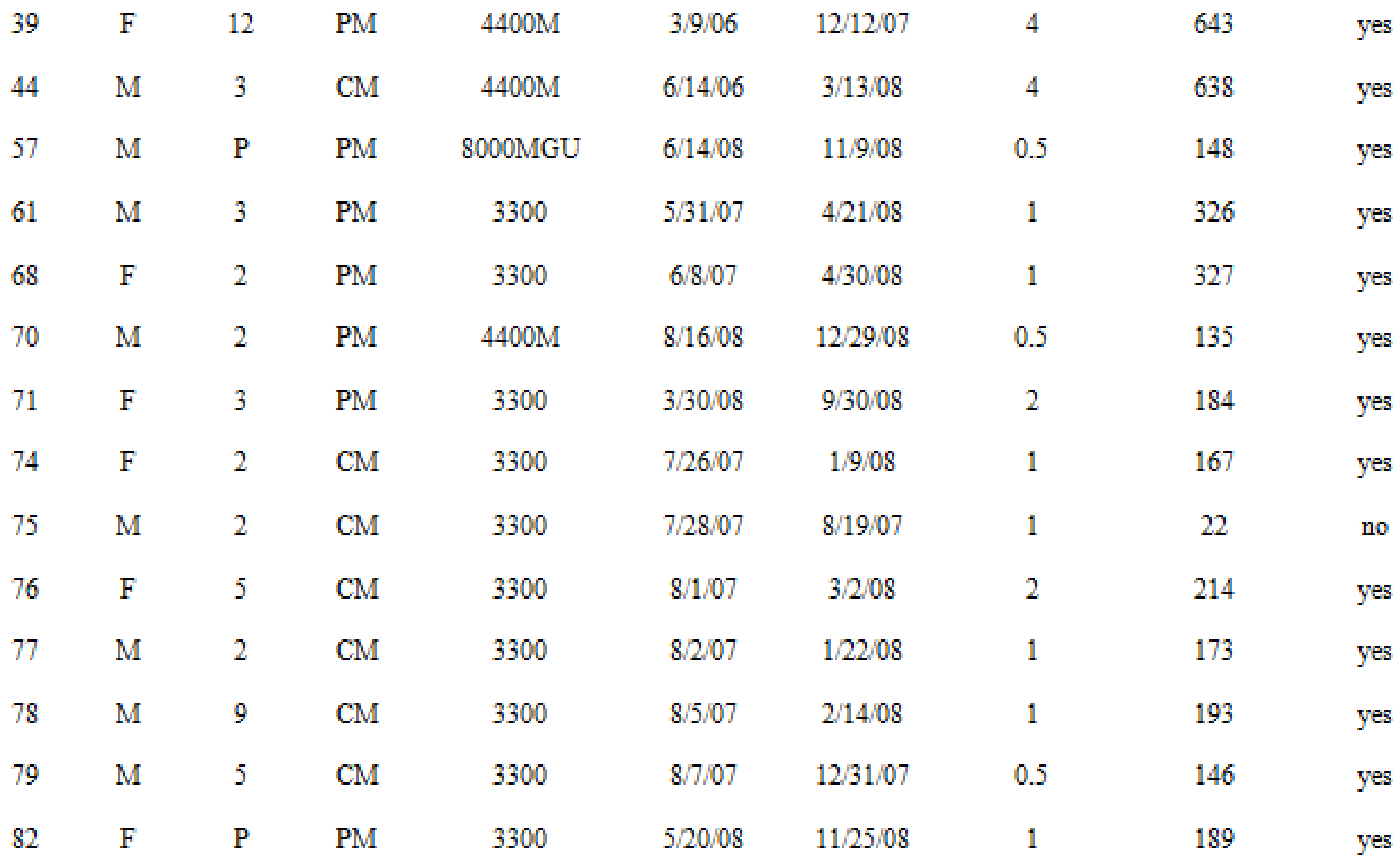
The black bear has recolonized southeastern Kentucky, and appears to be expanding into other portions of the state despite anthropogenic barriers. Road avoidance patterns in the present study varied in space and time, and across gender and regional boundaries. Such behavioral plasticity might enable bears to minimize exposure to road-related risks while accessing road-related benefits. However, despite avoidance of habitats near roads and selective crossing of roads, males of this population appear to be increasingly vulnerable to road mortality outside of the core area of distribution. Females are not known to have left the core area, a pattern consistent with low dispersal, but perhaps also driven by road avoidance. Continued investigations into how the Kentucky black bear is impacted by the barrier effect of roads and other anthropogenic influences will help to ensure the continued success of this newly-returned population.

APPENDICES

Appendix A. Identification of black bears captured and GPS-collared on Pine and Cumberland Mountains, Kentucky, 2005-08.

ID	Sex	Age[a]	Region[b]	Collar Model[c]	Start	End	Cycle (hrs)[d]	Duration (days)	Retained[e]
1	F	7	PM	4400M	3/20/06	10/26/07	4	585	yes
3	F	11	PM	3300	2/27/07	8/17/08	1	537	yes
4	M	3	PM	8000MGU	6/22/08	8/12/08	0.5	51	yes
5	F	5	PM	4400M	4/10/06	6/9/07	4	425	yes
11	M	7	PM	3300	7/15/06	8/10/06	4	26	no
12	M	7	PM	3300	5/18/05	5/17/06	4	364	yes
15	M	4	PM	3300	5/20/05	5/29/05	4	9	no
28	M	2	PM	4400M	7/19/06	6/6/07	4	322	yes
30	M	8	CM	3300	7/31/07	N/A	1	N/A	no
31	F	5	CM	3300	8/7/07	1/14/08	1	160	yes
37	F	3	PM	3300	4/10/06	6/1/07	1	417	yes

Appendix A (continued).



39	F	12	PM	4400M	3/9/06	12/12/07	4	643	yes
44	M	3	CM	4400M	6/14/06	3/13/08	4	638	yes
57	M	P	PM	8000MGU	6/14/08	11/9/08	0.5	148	yes
61	M	3	PM	3300	5/31/07	4/21/08	1	326	yes
68	F	2	PM	3300	6/8/07	4/30/08	1	327	yes
70	M	2	PM	4400M	8/16/08	12/29/08	0.5	135	yes
71	F	3	PM	3300	3/30/08	9/30/08	2	184	yes
74	F	2	CM	3300	7/26/07	1/9/08	1	167	yes
75	M	2	CM	3300	7/28/07	8/19/07	1	22	no
76	F	5	CM	3300	8/1/07	3/2/08	2	214	yes
77	M	2	CM	3300	8/2/07	1/22/08	1	173	yes
78	M	9	CM	3300	8/5/07	2/14/08	1	193	yes
79	M	5	CM	3300	8/7/07	12/31/07	0.5	146	yes
82	F	P	PM	3300	5/20/08	11/25/08	1	189	yes

Appendix A (continued).

83	M	P	PM	8000MGU	5/21/08	1/24/09	0.5	248	yes
85	M	P	PM	8000MGU	5/24/08	1/23/09	0.5	244	yes
86	M	P	PM	8000MGU	5/28/08	10/14/08	0.5	139	yes
87	M	P	PM	3300	5/30/08	12/13/08	0.5	197	yes
91	M	P	PM	3300	6/6/08	11/3/08	0.5	150	yes
93	F	P	PM	8000MGU	6/22/08	1/9/09	0.5	201	yes
94	M	P	CM	4400M	7/16/08	12/30/08	0.5	167	yes

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[a] Cementum age given in numbers (Matson's Laboratory LLC, Milltown, MT); *P* = pending laboratory results.

[b] PM=Pine Mountain, CM=Cumberland Mountain

[c] All collars were produced by Lotek Wireless, Inc (Newmarket, Ontario, Canada).

[d] Cycle refers to the pre-programmed interval between attempted GPS fixes.

[e] GPS location datasets were retained for analysis if they provided more than 30 days of data

Appendix B. Fixed kernel home range size of black bears used in road avoidance analyses, southeastern Kentucky, 2005-08.

ID	Sex	Region[a]	Active seasons[b]	50% kernel area (km^2)	95% kernel area (km^2)
1	F	PM	3	0.27	12.8
3	F	PM	3	3.28	31.5
5	F	PM	3	0.33	10.4
12	M	PM	3	1.17	22.2
28	M	PM	3	0.41	11.1
37	F	PM	3	1.03	15.8
39	F	PM	3	1.00	35.6
44	M	CM	3	20.7	228
57	M	PM	2	1.90	80.4
61	M	PM	2	0.28	31.2
68	F	PM	2	0.09	9.26
71	F	PM	3	1.13	13.8
74	F	CM	2	0.07	2.90
76	F	CM	2	0.19	4.29
77	M	CM	2	0.89	17.6
78	M	CM	2	5.04	46.6
82	F	PM	2	0.10	5.86
83	M	PM	2	11.7	177

Appendix B (continued).

85	M	PM	2	2.71	91.3
86	M	PM	2	0.57	27.7
87	M	CM	2	6.62	217
91	M	PM	2	1.78	87.8
93	F	PM	2	0.49	13.5
94	M	CM	2	1.08	80.2
Mean	M			4.22±3.22	85.9±40.9
Mean	F			0.73±0.55	14.2±6.21
Mean	All			2.62±1.87	53.0±26.3

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[b] PM=Pine Mountain, CM=Cumberland Mountain

[a] Active seasons refer to all but denning. Seasons per bear were retained if they included >10 days of GPS location data.

Appendix C. Fixed kernel home range size of female black bears used in road avoidance analyses by reproductive phase, southeastern Kentucky 2005-08.

ID	Phase[a]	Region[b]	Active seasons[c]	50% kernel area (km^2)	95% kernel area (km^2)
1	1	PM	3	0.07	7.09
1	2	PM	3	0.29	11.7
3	1	PM	2	0.10	4.85
3	2	PM	3	0.58	20.7
5	1	PM	2	0.31	5.08
5	2	PM	2	0.02	1.25
37	1	PM	2	0.14	5.57
37	2	PM	2	0.10	9.38
39	1	PM	3	0.06	3.02
39	2	PM	3	1.42	60.3
68	2	PM	2	0.01	0.26
71	1	PM	2	0.08	10.2
Mean	1			0.13±0.08	5.97±1.96
Mean	2			0.40±0.43	17.3±17.9

[a] 1=pregnant or caring for cubs of the year; 2=caring for yearlings or breeding

[b] PM=Pine Mountain, CM=Cumberland Mountain

[c] Active seasons refer to all but denning. Seasons per reproductive phase were retained if they included >10 days of GPS location data.

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VITA

Date of birth: September 25, 1975

Place of birth: Washington, D. C.

Education: University of Montana, Missoula

BA, Biology / Zoological Sciences

May 2004

Western Washington University, Bellingham

BA, English / Creative Nonfiction Writing

June 1998

Positions held: University of Kentucky, Lexington

Research Assistant

July 2006 – June 2008

University of Kentucky, Lexington

Teaching Assistant

January – May 2007

August – December 2007

University of Montana, Missoula

Biological Technician

January 2005 – July 2006

Swan View Coalition, Kalispell, Montana

Conservation Assistant

August – December 2004

Biomimicry Guild, Missoula, Montana

Information Coordinator

February 2003 – August 2004

Bureau of Land Management, Salem, Oregon

Biological Technician (Volunteer)

April – August 1995

Honors: National Science Foundation Graduate Research Fellowship

Honorable Mention

March 2004

Rebekah A. Jensen

December 10, 2009