Factors that Influence the Risk of Carnivore Road Mortality in Central Alabama

Forrest E. Cortes, *School of Forestry and Wildlife Sciences, 3301 SFWS Building, Auburn University, AL 36849*

Todd D. Steury, *School of Forestry and Wildlife Sciences, 3301 SFWS Building, Auburn University, AL 36849*

Abstract: Road mortality has been implicated as the most important transportation-related influence on wildlife populations; however, little is known about road mortality of carnivores in the pine-dominated landscapes of the Southeastern United States. We examined the influence of distance to vegetative cover, speed limit, distance to water, and distance to urban center on risk of road mortality to carnivores in central Alabama. We repeatedly drove an established route of six roads to search for road-killed carnivores during the first half of 2014 and used logistic regression to compare attributes of road-kill sites ($n = 99$) to an equal number of randomly selected sites. We found that for each 10-m decrease in distance to vegetative cover, a site was 1.21 (CL = 1.19–1.23) times as likely to be a road-kill site ($P = 0.044$). Our results suggest that transportation managers can positively affect carnivore mortality on roads by increasing the distance from road to cover.

Key words: Alabama, carnivores, road mortality, vegetative cover

Journal of the Southeastern Association of Fish and Wildlife Agencies 3:190–194

The construction and use of roadways is one of the most detrimental effects that humans can have on an ecosystem (Benítez-López et al. 2010, Fahrig and Rytwinski 2009, Trombulak and Frissell 2001). For example, roads fragment habitat and change dispersal patterns of species by acting as barriers (e.g., Riley et al. 2006, Shepard et al. 2008). Noise pollution from traffic disrupts local wildlife and results in decreased foraging efficiency for local predators that rely on sound to locate prey (e.g., Siemers and Schaub 2011). Pollution from vehicles on roadways introduces toxic compounds from vehicle exhaust and brake pads that degrade nearby ecosystem health (e.g., Legret and Pagotto 2006). Roadways also serve as a direct source of mortality for wildlife (Trombulak and Fressell 2001 and citations therein), and this effect has been implicated as the most important transportation-related influence on wildlife populations (Grilo et al. 2012, Bateman and Fleming 2012). Specifically, road mortality results in decreases in animal abundance, and consequently, a reduction of genetic diversity. Decreases in genetic diversity due to road mortality can even exceed that due to loss of habitat connectivity (Jackson and Fahrig 2011). Consequently, transportation planners and wildlife managers alike can benefit from an enhanced understanding of the ways that humans can mitigate the effects of roads on wildlife.

Carnivores may be an excellent model to study the effects of roadways on wildlife (Litvaitis et al. 2015). Medium- and large-sized carnivores in particular often experience disproportionately high mortality risk from roadways compared with other vertebrate groups (Fahrig and Rytwinski 2009, Noss et al. 1996). This increased risk can be attributed to the life history of carnivorous animals; terrestrial carnivores have large home ranges and typically must cross roadways at some point during their lives (Forman 2003, Riley et al. 2006). However, despite strong evidence linking road mortality to negative impacts on wildlife populations, knowledge about the distribution and composition of road mortality incidents is incomplete for many regions and landscapes. Moreover, given the importance of road mortality for many species' populations, more studies into the road characteristics that influence the risk of road mortality are warranted.

Previous studies have suggested that road characteristics are the most important factors driving road mortality rates of wildlife (e.g., Santos et al. 2013); however, little consensus exists about specifically how these factors can influence risk of road mortality in wildlife. For example, some studies suggest that most road mortality occurs on larger roads with higher speed limits (e.g., Jaarsma et al. 2006). Other studies suggest that smaller roads, with lower speed limits pose a greater risk to wildlife (e.g., van Langevelde et al. 2009). Similarly, although some studies have found that nearby water sources are not predictors for roadkill occurrence (e.g., Kanda et al. 2006), other studies have come to the opposite conclusion (e.g., Drews 1995, Langen et al. 2009). Previous studies often indicate that road mortality is higher in areas where the roadside is clear (e.g., Borkovcova et al. 2012); however, some authors have suggested that clearing roadside vegetation may reduce the risk of vehicle mortality for wildlife (Grilo et al 2012). While studies of such factors have been conducted internationally and in some parts of the United States, there have been few studies that analyze the factors that influence road mortality in the pine-dominated landscapes of the Southeastern United States.

In this study, we investigated the variables that may contribute to the risk of mortality of carnivores on roads in Central Alabama. We hypothesized that areas of road with higher speed limits would more likely be associated with carnivore mortality, as increases in vehicle speed have been related to increased risk of driver collisions in general (Aarts and van Schagen 2006), and that increased speed may decrease an animal's ability to detect oncoming traffic (Blackwell et al. 2014). We also hypothesized that areas closer to water and further from urban areas would more likely be associated with carnivore mortality, owing to increases in carnivore use of such areas and higher highway crossing rates by carnivores in these areas (Lewis et al. 2011). Finally, we hypothesized that areas of road with vegetative cover close to the road would more likely be associated with carnivore mortality as carnivores often associate with these habitats likely due to ease of travel along road corridors (Zimmermann et al. 2014) and increased prey species abundance along roadside edge habitat (Bellamy et al. 2000, Banding 2006, Hwang et al. 2007). We examined the influence of speed limit, distance from roadkill incident to nearest water, distance-from roadkill incident to nearest vegetative cover, and distance from roadkill incident to urban center on risk of carnivore road mortality in central Alabama, a pine-dominated landscape.

Methods

We sampled for road-killed animals along established routes and compared attributes of road-kill sites to randomly selected sites along the same routes. In the establishment of survey routes, we selected six routes that fit the following parameters: greater than 30 km in length, located in east-central Alabama (See Figure 1), and were a 2- or 4-lane highway. The natural areas adjacent to these routes featured similar habitat types: pine-dominated forests common to the region. The selected routes covered a total of 380 km.

We drove the routes and located carcasses between January and June of 2014. The timing of our data collection allowed us to sample during the spring season, a period that has been associated with increased rates of road mortality in carnivores (Murray and St. Clair 2015). Each round of sampling included six routes, which were sampled within a few days of one another. We conducted four rounds of sampling, with approximately 20 days between each round. Timing between sampling periods was based on available persistence data for carcasses on the road (Santos et al. 2011). We drove routes at moderate speeds in order to locate small carcasses for identification. Each carnivore carcass was identified to species and the location of the carcass was recorded using a GPS device. Only carcasses on the shoulders of the road were included in the survey. A few carcasses were not identifiable to species, and were not included in the analysis.

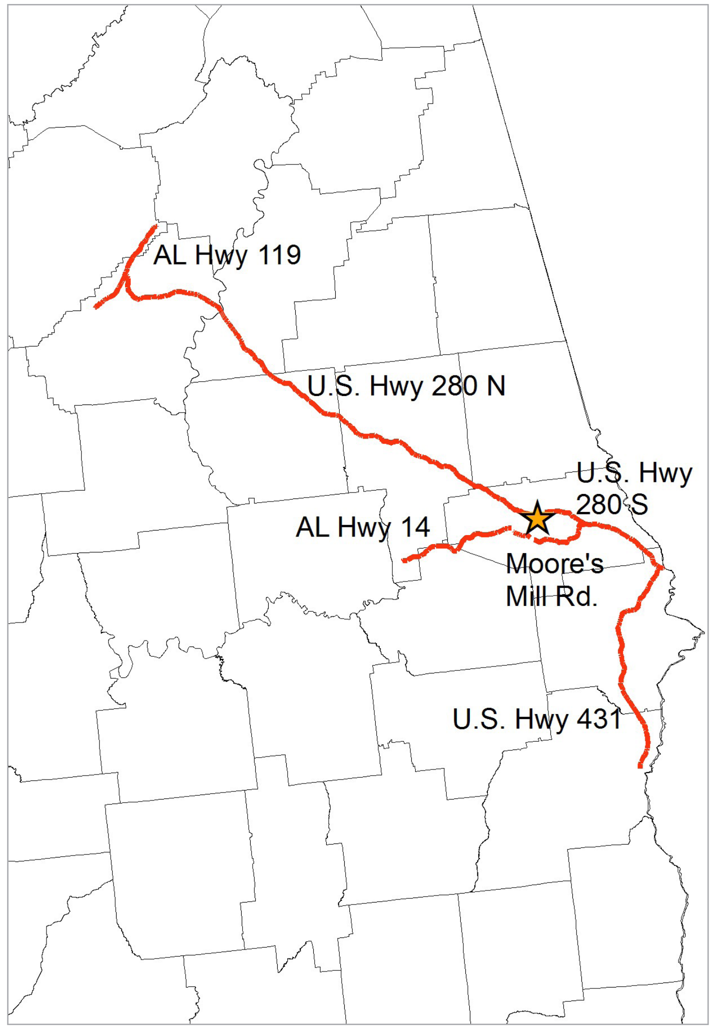

Figure 1. Select road routes we surveyed for carnivore carcasses within the highlighted region of east-central Alabama. The star is Auburn, Alabama, which served as the starting point for all survey routes.

Locations of carcasses were entered into an ArcMAP 10.1 database (Environmental Systems Research Institute, Inc., Redlands, California) in order to assess attributes of locations. Random locations were generated using the 'Create Random Points' tool in ArcMAP; an equal number of random points were generated to the number of carcass locations. For each carcass and random location we calculated distance to the nearest urban area, defining "an urban area" as Developed High Intensity according to the National Land Cover Database (Homer et al. 2015); distance to the nearest body of water, where "water" was any area classified as water by the National Land Cover Database (Homer et al. 2015); speed limit, which was extracted from a GIS layer provided to us by the Alabama Department of Transportation (ALDOT); and distance to nearest vegetative cover, which was calculated using the measurement tool in Google Earth as the straight-line distance from the location of the carcass to the edge of the nearest visible vegetative cover on the side of the road or in the median. Distance to water and distance to urban area were calculated in ArcGIS 10.1 (ESRI 2012) using the 'Near' tool.

To examine statistically the risk of road mortality as a function of the various factors, we ran a mixed-effects logistic regression in program R (R Project for Statistical Computing 2015) with road-kill or random site as the response variable and distance to urban area, distance to water, distance to vegetative cover, and speed limit as independent variables in a full model. Significance of individual variables was assessed using a partial-likelihood-ratio test. The route was included in the model as a random variable, as randomly-generated points were not stratified by route to match the number of carcass locations. We present the results as odds ratios, which compare the relative odds of a site being a road-kill site rather than a random site, as a function of the independent variable (Hosmer and Lemeshow 2000). We deemed that variables were significant at $P = 0.05$.

Results

We found 99 carnivore road-kill carcasses, including 68 Virginia opossum (*Didelphis virginiana*; 59.6%), 28 raccoon (*Procyon lotor*; 24.6%), 3 gray fox (*Urocyon cinereoargenteus*; 2.6%), 2 striped skunk (*Mephitis mephitis*; 1.8%), 1 coyote (*Canis latrans*; 0.9%), and 1 bobcat (*Lynx rufus*; 0.9%).

Logistic regression revealed that as distance to vegetative cover decreased, a site was more likely to be a road-kill site. Specifically, for each 10-m decrease in distance to vegetative cover, a site was 1.21 (CL = 1.19–1.23) times as likely to be a road-kill site ($P = 0.044$). None of the other variables were statistically significant in our analyses ($P > 0.091$; Table 1). Notably, we conducted a sub analysis of just the raccoon and opossum data; the results were nearly identical to those attained using the full dataset.

Table 1. Results of logistic regression analysis examining the relationship between probability that a site was a road-kill site and various independent variables. Reported results are from a full model with all variables. Route was included as a random effect.

Variable (units)	Odds ratio	C.L. on odds ratio	*p* - value
Distance to vegetation (m)	1.019	1.018–1.021	0.044
Distance to urban area (km)	1.08	0.99–1.18	0.091
Distance to water (km)	1.47	0.86–2.52	0.153
Speed limit (mph)	1.03	0.99–1.08	0.145

Discussion

The only variable that was significantly related to the risk of mortality in this study was distance to vegetative cover. This finding is consistent with other studies that have found that increased vegetative cover along roadsides may heighten the risk of road mortality for certain taxonomic groups (Bellis and Graves 1971, Clevenger et al. 2003, Hodson 1962, Jochimsen et al. 2014). We suspect that roads near vegetative cover likely pose a heightened risk to carnivores because carnivores rely on vegetative areas as both direct and indirect sources of food (Grilo et al. 2012, Roemer et al. 2009). If carnivores spend more time in these favored edge habitats, it seems logical that roadways located closer to that edge would bring carnivores closer to vehicles which could lead to increased mortality. Finally, many carnivores attempt to minimize time in the open, especially open habitats that are associated with humans, such as roadways (Grilo et al. 2012). Thus, carnivores may be more likely to cross roadways when the distance across the roadway is smaller, as is the case when vegetation is close to the road. However, we note that our study was done exclusively in the spring, and thus we cannot assess how our results might have been different during other periods of the year (e.g., summer/fall) when resource abundance may be more scarce or carnivores may be engaging in different spatial behaviors (e.g., mate searches, dispersal movements).

Driver characteristics in areas with dense vegetation may also help explain the increased risk to wildlife in areas where the roadway is close to vegetative cover. A study by Fitzpatrick et al. (2014) found that drivers were more likely to exceed posted speed limits on roads with dense vegetation and little clear space along the road. Oncoming vehicles moving at higher speeds may be more difficult for wildlife to avoid than slower moving vehicles, thus leading to an increased risk of mortality when wildlife attempt to cross these roadways.

None of the other variables examined in our study were significantly related to risk of road mortality, although estimates of effect and measures of uncertainty (confidence limits and *p*-values) suggest that the factors may have been statistically significant if greater sample sizes were attained. Indeed, some of these variables have been important in previous studies: for example, speed limit appears to influence mortality in certain herbivore species (Dique et al. 2003) although other researchers have found that road mortality for other taxonomic groups was unrelated to speed limit (Bissonette and Kassar 2008). A lack of relationship between risk of mortality and speed limit may be due to the ability of wildlife to behaviorally adapt to the speed of oncoming vehicles, as suggested by studies for other taxonomic groups (DeVault et al. 2014, DeVault et al. 2015, Legagneux and Ducatez 2013, Lima et al. 2015). Additional sampling and analysis is needed to further clarify observed trends.

In our study, we did not have estimates of traffic volume for our routes, which may have imposed limitations on the scope of our understanding about the factors that influence carnivore road mortality. Previous studies have indicated that traffic volume has an influence on habitat use by carnivores (Whittington et al. 2005), so it is possible that this variable could also influence road mortality frequency for this taxonomic group. In order to better understand the factors that influence carnivore road mortality, wildlife managers and highway agencies should collaborate to collect usable traffic volume data which remains unavailable for many regions and roadways. Similarly, a number of other variables which we did not collect might influence risk of mortality to carnivores. These include degree of road-way lighting or the existence of culverts or other crossing structures. Finally, we also did not attempt to estimate carnivore density or habitat quality near road ways. Such information could be useful in further elucidating the characteristics of roads that make them particularly dangerous to carnivores.

Management Recommendations

Wildlife managers and urban planners alike can use the results of this study to help mitigate vehicle-wildlife collisions. Our study suggests that managers can positively affect wildlife near roadways by increasing distance between roads and proximate vegetative cover. Managers can also utilize the results of this study to assist in the locating of spatial hotspots, or high-risk areas, for vehicle-wildlife collisions which other authors suggest is the first step in the reduction of such collisions (Litvaitis and Tash 2008, Ramp et al. 2005). While the alteration of roadside edges may not be cost-effective on a large scale, the concentration of mitigation efforts in hotspot areas might be a way to improve the efficiency of these efforts (Meisingset et al. 2014).

Acknowledgments

We thank the Auburn University Undergraduate Research Fellowship Program and the School of Forestry and Wildlife Sciences for the funding of this study. We also thank Mike Rief at the Alabama Department of Transportation for providing speed limit data, and M. Fidino and B. Patterson whose useful comments greatly improved the manuscript.

Literature Cited

Aarts, L. and I. van Schagen. 2006. Driving speed and the risk of road crashes: a review. Accident Analysis & Prevention 38:215–224.

Bateman, P.W. and P.A. Fleming. 2012. Big city life: carnivores in urban environments. Journal of Zoology 287:1–23.

Barding, E.E. 2006. Movements and habitat selections of raccoons in a rural Illinois landscape. Master's Thesis. Eastern Illinois University, Charleston.

Bellamy, P.E. et al. 2000. Road verges as habitat for small mammals in Britain. Mammal Review 30:131–139.

Bellis, E.D. and H.B. Graves. 1971. Deer mortality on a Pennsylvania interstate highway. Journal of Wildlife Management 35:232–237.

Benítez-López, A., R. Alkemade, and P.A. Verweij. 2010. The impacts of roads and other infrastructure on mammal and bird populations: a meta-analysis. Biological Conservation 143:1307–1316.

Bissonette, J.A. and C.A. Kassar. 2008. Locations of deer-vehicle collisions are unrelated to traffic volume or posted speed limit. Human-Wildlife Conflicts 2:122–130.

Blackwell, F.B., T.W. Seamans, and T.L. DeVault. 2014. White-tailed deer response to vehicle approach: evidence of unclear and present danger. DOI:10.1371/journal pone 0100988

Borkovcova, M., J. Mrtka, and J. Winkler. 2012. Factors affecting mortality of vertebrates on the roads in the Czech Republic. Transportation Research Part D 17:66–72.

Clevenger, A.P, B. Chruzcz, and K.E. Gunson. 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. Biological Conservation 109:15–26.

DeVault, T.L., B.F. Blackwell, T.W. Seamans, S.L. Lima, and E. Fernández-Juricic. 2014. Effects of vehicle speed on flight initiation by turkey vultures: implications for bird-vehicle collisions. DOI:10.1371/journal pone.0087944.

———, ———, ———, ———, and ———. 2015. Speed kills: ineffective avian escape responses to oncoming vehicles. Proceedings of the Royal Society B: Biological Sciences 282:20142188.

Dique, D.S., J. Thompson, H.J. Preece, G.C. Penfold, D.L. de Villiers, and R.S. Leslie. 2003. Koala mortality on roads in south-east Queensland: the koala speed-zone trial. Wildlife Research 30:419–426.

Drews, C. 1995. Road kills of animals by public traffic in Mikumi National Park, Tanzania, with notes on baboon mortality. African Journal of Ecology 33:89–100.

ESRI.2013. ArcMap, version 10.2. ESRI, Redlands, California.

Fahrig, L. and T. Rytwinski. 2009. Effects of roads on animal abundance: an empirical review and synthesis. Ecology and Society 14:21.

Fitzpatrick, C.D., C.P. Harrington, M.A. Knowdler, Jr., and M.R. Romoser. 2014. The influence of clear zone size and roadside vegetation on driver behavior. Journal of Safety Research 49:97–104.

Forman, R.T.T. 2003. Road Ecology: Science and Solutions. Island Press, Washington, D.C.

Grilo, C., J. Sousa, F. Ascensão, H. Matos, I. Leitão, P. Penheiro, M. Costa, J. Bernardo, D. Reto, R. Lourenço, M. Santos-Reis, and E. Revilla. 2012. Individual spatial responses towards roads: implications for mortality risk. DOI:10.1371/journal pone.0043811.

Hodson, N.L. 1962. Some notes on the causes of bird road casualties. Bird Study 9:168–173.

Hosmer, D.W. and S. Lemeshow. 2000. Applied logistic regression. John Wiley & Sons, Inc., Hoboken, New Jersey.

Hwang, Y.T., S. Lariviere, and F. Messier. 2007. Local- and landscape-level den selection of striped skunks on the Canadian prairies. Canadian Journal of Zoology 85:33–39.

Jaarsma, C. F., F. van Langevelde and H. Botma. 2006. Flattened fauna and mitigation: Traffic victims related to road, traffic, vehicle, and species characteristics. Transportation Research Part D 11:264–276.

Jackson, N. and L. Fahrig. 2011. Relative effects of road mortality and decreased connectivity on population genetic diversity. Biological Conservation 144:3143–3148.

Jochimsen, D.M., C.R. Peterson, and L.J. Harmon. 2014. Influence of ecology and landscape on snake road mortality in a sagebrush-steppe ecosystem. Animal Conservation 17:583–592.

Kanda, L.L., T.K. Fuller, and P.R. Sievert. 2006. Landscape associations of road-killed Virginia opossums (*Didelphis virginiana*) in central Massachusetts. American Midland Naturalist 156:128–134.

Langen, T.A., K.M. Ogden, and L.L. Schwarting. 2009. Predicting hot spots of herpetofauna road mortality along highway networks. Journal of Wildlife Management 73:104–114.

Legagneux, P. and S. Ducatez. 2013. European birds adjust their flight initiation distance to road speed limits. Biology Letters 9:20130788.

Legret, M. and C. Pagotto. 2006. Heavy metal deposition and soil pollution along two major rural highways. Environmental Technology 27:247–254.

Lewis, J.S., J.L. Rachlow, J.S. Horne, E.O. Garton, W.L. Wakkinen, J. Harden, and P. Zager. 2011. Identifying habitat characteristics to predict highway crossing areas for black bears within a human-modified landscape. Landscape and Urban Planning 101:99–107.

Lima, S.L., B.F. Blackwell, T.L. DeVault, and E. Fernández-Juricic. 2015. Animal reactions to oncoming vehicles: a conceptual review. Biological Reviews 90:60–76.

Litvaitis, J.A. and J.P. Tash. 2008. An approach toward understanding wildlife-vehicle collisions. Environmental Management 42:688–97.

———, G.C. Reed, R.P. Carroll, M.K. Litvaitis, J. Tash, T. Mahard, D.J.A. Broman, C. Callahan, and M. Ellingwood. 2015. Bobcats (*Lynx rufus*) as a model organism to investigate the effects of roads on wide-ranging carnivores. Environmental Management 55:1366–1376.

Meisingset, E.L., L.E. Loe, O. Brekkum, and A. Mysterud. 2014. Targeting mitigation efforts: the role of speed limit and road edge clearance for deer-vehicle collisions. Journal of Wildlife Management 78:679–688.

Murray, M.H and C. St. Clair. 2015. Individual flexibility in nocturnal activity reduces risk of road mortality for an urban carnivore. Behavioral Ecology 26:1520–1527.

Noss, R.F., H.B. Quigley, M.G. Hornocker, T. Merrill, and P.C. Paquet. 1996. Conservation biology and carnivore conservation in the Rocky Mountains. Conservation Biology 10:949–963.

Ramp, D., J. Caldwell, K.A. Edwards, D. Warton, and D.B. Croft. 2005. Modelling of wildlife fatality hotspots along the Snowy Mountain Highway in New South Wales, Australia. Biological Conservation 126:474–490.

Riley, S.P.D., J.P. Pollinger, R.M. Sauvajot, E.C. York, C. Bromley, T.K. Fuller, and R.K. Wayne. 2006. A southern California freeway is a physical and social barrier to gene flow in carnivores. Molecular Ecology 15:1733–1741.

Roemer, G.W., M.E. Gompper, and B. van Valkenburgh. 2009. The ecological role of the mammalian mesocarnivore. BioScience 59:165–173.

Santos, S.M., F. Carvalho, and A. Mira. 2011. How long do the dead survive on the road? Carcass persistence probability and implications for road-kill monitoring surveys. DOI:10.1371/journal pone. 0025383

———, R. Lourenco, A. Mira, and P. Beja. 2013. Relative effects of road risk, habitat suitability, and connectivity on wildlife roadkills: the case of tawny owls (*Strix aluco*). DOI:10.1371/journal pone. 0079969

Siemers, B.M. and A. Schaub. 2011. Hunting at the highway: traffic noise reduces foraging efficiency in acoustic predators. Proceedings of the Royal Society of London, Series B 278:1646–1652.

Shepard, D.B., A.R. Kuhns, M.J. Dreslik, and C.A. Phillips. 2008. Roads as barriers to animal movement in fragmented landscapes. Animal Conservation 11:288–296.

Trombulak, S.C. and C.A. Frissell. 2001. Review of the ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:8–30.

van Langevelde, F., C. van Dooremalen, and C.F. Jaarsma. 2009. Traffic mortality and the role of minor roads. Journal of Environmental Management 90:660–667.

Whittington, J., C.C. St. Clair, and G. Mercer. 2005. Spatial responses of wolves to roads and trails in mountain valleys. Ecological Applications 15:543–553.

Zimmermann, B., L. Nelson, P. Wabakken, H. Sand, and O. Liberg. 2014. Behavioral responses of wolves to roads: scale-dependent ambivalence. Behavioral Ecology 25:1353–1364.