Title

A Proposed Analysis of Deer Use of Jumpout Ramps and Wildlife Use of Culverts along a Highway with Wildlife Exclusion Fencing

Journal

Proceedings of the Vertebrate Pest Conference, 28(28)

ISSN

0507-6773

Authors

Jensen, Alex J.
Perrine, John D.
Siepel, Nancy
et al.

Publication Date

2018

DOI

10.5070/V42811026

A Proposed Analysis of Deer Use of Jumpout Ramps and Wildlife Use of Culverts Along a Highway with Wildlife Exclusion Fencing

Alex J. Jensen and **John D. Perrine**
Biological Sciences Department, California Polytechnic State University, San Luis Obispo, California
Nancy Siepel and **Morgan Robertson**
California Department of Transportation, District 5, Environmental Division, San Luis Obispo, California

ABSTRACT: Highways can fragment habitat and be a significant mortality source for mammals. Wildlife exclusion fencing has been shown to reduce wildlife-vehicle collisions, but can also prevent animals from escaping the highway corridor if they enter at access roads or at fence ends. Earthen escape ramps, or "jumpouts," have been proposed as a possible solution but remain relatively untested. From 2012-2014, we used wildlife cameras to continuously document wildlife use of four jumpout ramps constructed as part of a 2.5-mile wildlife exclusion fence project along Highway 101 near San Luis Obispo, California. Mule deer occasionally used the jumpouts, but quantifying the rate of utilization was confounded by repeated visits by the same individuals. Male and female deer appeared to have different responses to the jumpouts, which warrants deeper investigation using additional data collected from further monitoring through mid-2017. The longer dataset will also better document how individual deer learn to use the jumpouts. Fenced highways can also reduce connectivity unless there is sufficient use of crossing structures. We documented mountain lion, bobcat, black bear, and mule deer used culverts and underpasses in and adjacent to the wildlife fence zone from 2012-2014. Mule deer used the large underpasses almost exclusively, and rarely if ever used culverts. Bear used a wider variety of structures, and bobcats were detected at almost every site and at a higher rate than the other taxa. Mountain lion detections were quite rare, likely due to lower population density in the study area. We propose a deeper multivariate analysis of the factors influencing these species' use of culverts including culvert dimensionality, nearby habitat, and proximity to cover, based on an expanded dataset of up to five years of continual monitoring at certain sites. The goal of these analyses is to provide information that will help reduce wildlife-vehicle collisions while facilitating regional wildlife connectivity.

KEY WORDS: jumpouts, mule deer management, *Odocoileus hemionus*, road ecology, wildlife cameras, wildlife corridors, wi ldlife crossings, wildlife-exclusion fencing, wildlife-vehicle collisions

Proc. 28th Vertebr. Pest Conf. (D. M. Woods, Ed.)
Published at Univ. of Calif., Davis. 2018. Pp.145-151.

INTRODUCTION

Roads have significant ecological impacts, with multiple direct and indirect effects upon habitat structure and wildlife populations (Forman and Alexander 1998). Wildlife-vehicle collisions (hereafter WVCs) and resulting roadkill are the most familiar and socially relevant consequences of interactions between roads and wildlife. In the United States, WVCs account for about 5% of all reported vehicular collisions (Clevenger and Huijser 2011), and many more doubtless go unreported, especially those involving smaller species (Garbutt 2009). WVCs often cause the death of the animal struck, and this can be a significant population-level mortality factor for taxa such as Florida panther (*Puma concolor coryi*) and Key white-tailed deer (*Odocoileus virginianus clavium*; Forman and Alexander 1998). WVCs involving large-bodied animals such as deer (*Odocoileus* sp.) can also be costly to humans: deer-vehicle collisions cause 150-200 human deaths, >29,000 human injuries annually, and cause damages averaging >$6,600 per collision (Mastro et al. 2008, Huijser et al. 2009, Stull et al. 2011).

Multiple studies have documented that wildlife exclusion fencing can significantly reduce the number of animals on the highway and thereby reduce the risk of WVCs (Mastro et al. 2008, Stull et al. 2011, Rytwinski et al. 2016). Huisjer et al. (2015) found that well-designed, implemented, and maintained wildlife exclusion fencing resulted in an 80-100% reduction in WVCs involving large mammals. Even with wildlife exclusion fencing, complete elimination of WVCs may be impossible because animals may still enter the highway corridor via ungated access roads and other gaps, and at the ends of the exclusion fence (Clevenger et al. 2001). In these circumstances, the wildlife exclusion fence may now trap animals in the highway corridor, thereby increasing the probability of a WVC. To prevent this problem, infrastructure such as one-way gates and earthen jumpout ramps have been proposed to allow animals to escape from the highway corridor (Bisonnette and Hammer 2000). Several recent studies have examined wildlife use of jumpout ramps, particularly by ungulates, and the associated reduction in WVCs. For example, Gagnon et al. (2013) found that bighorn sheep (*Ovis canadensis*) in Arizona jumped out in 96% of their detection events on the ramps, and Siemers et al. (2015) found that installing jumpouts caused a significant reduction in the rate of WVCs involving mule deer (*O. hemionus*). However, questions remain regarding wildlife use of jumpouts, even by closely-related species. Additionally, studies <2 year may not allow sufficient time to document how species to learn to use the jumpouts (Clevenger and Huijser 2011).

In addition to the direct effects of WVC mortality, roads can also have significant indirect effects, especially barrier (Poessel et al. 2014) or filtration (Clevenger and Waltho 2005) effects on wildlife movement. Carnivores (especially large ones) are particularly vulnerable to habitat fragmentation because of their relatively large ranges, low population density, and conflicts with (and persecution by) humans (Crooks 2002). Van Dyke et al. (1986) documented mountain lion (*Puma concolor*) home ranges to be in areas with relatively low road densities, most likely meaning that mountain lions avoid areas with higher densities of roads. Highways can cause increased mortality and reduced gene flow even for smaller, more adaptable carnivores such as coyote (*Canis latrans*) and bobcat (*Lynx rufus*; Riley et al. 2003, 2006). The addition of wildlife exclusion fencing may further increase a highway's barrier effect, unless there is sufficient movement through undercrossings, culverts, and similar structures (Huijser et al. 2015).

The objective of our study was to quantify wildlife use of jumpouts, culverts and underpasses associated with a recently-installed wildlife exclusion fence along a major highway. Our focal species were mule deer, black bear, mountain lion, and bobcat. The larger-bodied species may pose a human safety risk due to WVCs, and have comparably low population densities and require large home ranges. Bobcats have been identified as a "fragmentation-sensitive species" (Poessel et al. 2014), have been used as an ecological indicator of habitat fragmentation in California (e.g., Jennings 2013), and are representative of the mesocarnivores guild which plays important ecological roles such as mediating trophic cascades (Roemer et al. 2009). Here we present a preliminary analysis of the first 2 years of data collection (2012-2014) and discuss our plans for a more detailed analysis of the full dataset (2012-2017). A better understanding of wildlife use of jumpouts, culverts and underpasses can guide future construction and retrofitting to reduce the risk of WVCs while facilitating landscape connectivity.

METHODS

Study Site

U.S. Highway 101 in San Luis Obispo County, California, is a major regional transportation corridor, with traffic volume of up to 4,000 vehicles per hour (Snyder 2014). Just north of the city of San Luis Obispo, the highway crosses through the Santa Lucia Mountains, an area dominated by natural land cover and part of the Los Padres National Forest. Computer modeling has identified this area as an important regional and local movement corridor for large mammals such as mountain lion, mule deer and black bear (Thorne et al. 2006, Thorne and Huber 2011), and field surveys have indicated that this area is a hotspot for roadkills of these taxa (Siepel et al. 2013). To minimize large-mammal roadkills and protect human safety, the California Department of Transportation (hereafter, Caltrans) constructed a 2.5 mile wildlife exclusion fence, including four earthen "jumpout ramps," through the wildlife hotspot in April 2012. Each jumpout consists of an earthen ramp extending from the highway right of way (ROW) to the edge of the wildlife exclusion fence, with a vertical drop of approximately 6.5 ft. (project and infrastructure details in Siepel et al. 2013, Perrine 2015.)

Data Collection

To document deer use of the jumpout ramps, we used Reconyx HC600 Hyperfire cameras (Reconyx, Holmen, WI) with a motion-activated trigger and infrared flash. One camera was mounted at the top of each jumpout, aimed to photograph animals using the ramp and record whether they jumped out. Data collection occurred continuously from July 2012 through August 2017. To monitor wildlife use of culverts and underpasses in our study site, we used Reconyx HC600 Hyperfire or Bushnell TrophyCam HD (Bushnell Outdoor Products, Overland Park, KS) cameras. There were dozens of culverts of various sizes within and adjacent to the wildlife exclusion fence area, so we focused only on those large enough to accommodate our focal species (width and height of ≥4ft). This criterion was met by four culverts within the wildlife exclusion fence zone, five culverts adjacent to the wildlife exclusion fence zone, and two larger undercrossings at the ends of the wildlife exclusion fence. We used one camera per culvert, usually near the midpoint to document wildlife actually crossing through the culvert; 2-3 cameras were necessary at each of the large undercrossings (for details, see Perrine 2015). Monitoring began in August 2012 and the duration varied by site due to theft or removal due to the risk of theft. Cameras at jumpouts, culverts and underpasses were checked every 3-4 weeks to collect the photos and ensure that the camera was still in good working order.

Data Analysis

We reviewed the photographs and recorded the number of *detection events* for each focal species. A single detection event represents the presence of a species at a camera site at a certain time, and could consist of dozens of individual photographs. For each detection event for a species at a site, we recorded the date, time, and number of individuals involved. For detection events at jumpouts, we also recorded whether the animals jumped out or not; events with ambiguous outcomes were excluded from further analysis. We used a minimum time of 15 min to separate detection events of the same species at the same site; in other words, at least 15 min had to pass with no detections in order for a visit to not be considered part of the previous event by that species at that site. To facilitate comparisons among sites and species, the number of detection events for each species was standardized by dividing by the number of nights the camera was fully operational at that site, yielding *detection events per survey night*. This value could be multiplied by the average group size for a species at a site to give the *total activity per survey night* for that species at that site (Perrine 2015). Months with <10 survey days at a site (due to camera failure, theft, etc.) were excluded from our analyses.

RESULTS

Jumpouts

From July 2012 through July 2014, the cameras at the four jumpouts generated a total of 121,350 photographs over 2,864 survey nights, and yielded a total of 431 animal detection events. Camera performance was generally good, so the number of survey nights was roughly equivalent among sites, ranging from 703-728 nights. In contrast, the number of animal detection events varied widely among sites, from 38 to 207. Deer were by far the most frequently detected species, accounting for 363 (84.3%) of the 431 wildlife events on the jumpout ramps. Other species detected on the ramps included gray fox

(*Urocyon cinereoargenteus*; 38 events), raccoon (*Procyon lotor*; 6), coyote (3), red fox (*Vulpes vulpes*; 2), bobcat (2), and black bear (*Ursus americanus*; 1). Mountain lion, feral pig (*Sus scrofa*), badger (*Taxidea taxus*), and striped skunk (*Mephitis mephitis*) were not detected on the ramps.

Deer did jump off the ramps (Figure 1a) but this outcome was rare, occurring in only 6% of the deer detection events. In the remaining events, the deer returned back toward the highway ROW, sometimes after lounging at the top of the ramp for considerable time (Figure 1b). Many of these events appeared to involve the same individual deer returning day after day, even though they did not jump out. Deer never used the ramps to enter the highway corridor from outside the exclusion fence.

Culverts and Underpasses

We deployed a total of 14 cameras in the culverts and underpasses, which generated approximately 149,000 photographs over 7,568 survey nights. The number of survey nights per site varied from 196 to 708 (Table 1), because the cameras were not deployed simultaneously and several were stolen. The number of animal detection events also varied among sites, from 83 to 639 per sites. Standardizing by the number of survey nights yielded detection events per survey night ranging from 0.13 to 1.60. Deer were the most frequently detected of our four focal species, but their use of the structures varied widely by site. They primarily used the large underpasses at each end of the wildlife exclusion fence, and were rarely detected using culverts, even the large drive-through culverts located just north of the wildlife exclusion fence zone. In contrast, bear activity was more balanced across the sites. They used even the smallest monitored culverts, although we did not detect them at the largest underpass or at several large drive-through culverts. Mountain lion detections were rare and occurred at only three of the 11 sites, with a single culvert accounting for most of the activity. Bobcats used virtually all of the culverts and underpasses, though their rate of activity varied widely, from 0.45 to 0.01 animals per survey night per site.

DISCUSSION

Jumpouts

Within days of deploying cameras at the jumpouts, we obtained conclusive evidence that at least some deer will use them to exit the highway ROW (Figure 1a). Unfortunately, this was fairly uncommon, and moreover it was not straightforward to use the detections to calculate a probability of use due to the repeated visits by what appeared to be the same individual deer. If the same individuals are returning day after day, then the detection events at a site are not independent events but instead pseudoreplicates (Hurlbert 1984). Therefore, the observed proportion of events that result in jumping out would not be a robust indicator of the probability of any given deer using the jumpout ramp to escape the highway ROW. This phenomenon is not unique to this project; for example, a study in Georgia found that one individual deer accounted for >50% of 1,400 highway crossings recorded in one year (Stickles 2015). Jumping out may be a learned behavior, and it is possible that as the local deer become comfortable jumping out, they will incorporate this into their daily movement patterns, which would result in a sharp increase in the proportion of events resulting in jumping out. Documenting the time necessary for deer to acclimate to the jumpouts would be a useful contribution to the broader understanding of the ecological effectiveness of the jumpouts, and our 5-year dataset would likely be better than shorter-duration studies in documenting this phenomenon (Clevenger and Huijser 2011).

Our preliminary data analysis also suggests that the probability of jumping out may differ between bucks and does, and that solitary deer may be more likely to jump out than deer in a group, especially if the group contains fawns. Because we have continued to collect data at these sites, we now have a continuous 5-year data series, comprising >575 detections of deer on the jumpout ramps, which we can use to address these more complex questions. Examining gender-based differences in the rate of jumping out will require excluding events during February through April when many male deer in our study area do not bear antlers and therefore cannot be confidently differentiated from females. Our planned analyses also include attempting to identify individual deer so that we can account for repeated visits, and examining the long-term trend that may result when deer learn how to use (or become comfortable using) the jumpouts to escape the highway ROW. As the decision of whether or not to jump out is an individual one, it would be ideal document the movement patterns of individual deer via GPS

Figure 1. Mule deer photographed on the jumpout ramps along Highway 101 in San Luis Obispo County, California. a) Buck jumping out. b) Doe and fawn browsing at the top of the ramp but not jumping out.

Table 1. Dimensions and survey effort for each camera deployed in undercrossings starting in 2012. We used three cameras to survey Santa Margarita Creek underpass, and two for the Railroad underpass. Camera sites C03 and C04 were not included in this analysis. Location: F = Fence zone; N = North of fence zone; S = South of fence zone; N end = North end of fence; S end = South end of fence. Organized from largest to smallest starting at the top. Both of the underpasses are divided but the length includes the uncovered portion. Animal detections per survey day is for all taxa, not just the four focal species.

Site	Location	Dimensions: Height, Width, Length (feet)	Total Survey Days	Animal Detections	Animal Detections per Survey Day
Santa Margarita Creek	N end	20, 110, 51.5			
North bank (C11)			232	371	1.60
Center channel (C12)			196	97	0.49
South bank (C13)			196	139	0.71
Railroad flyover	S end	30, 180, 125			
North side (C15)			317	177	0.56
South side (C16)			653	348	0.53
Tassajara Creek (C05)	F	9.70, 13.20, 161	708	388	0.55
N10.0 (C08)	N	12.10, 8.30, 125	653	83	0.13
N 8.5 (C06)	N	11.70, 12, 144.25	701	639	0.91
N 9.1 (C07)	N	7.25, 8.30, 155	694	215	0.31
Woods Winery (C01)	S	8, 6, 139.60	644	233	0.36
N 3.1 (C02)	S	8.80, 6, 168	614	522	0.85
Water District (C14)	F	4, 8, 170	707	201	0.28
Highway 58N (C10)	F	3.25, 4.33, 217.25	566	308	0.54
Highway 58S (C09)	F	3.50, 4, 98.83	687	333	0.48

telemetry so we can observe their fine-scale movement patterns through the highway ROW (Kramer et al. 2016).

Undercrossings

Our two-year dataset revealed clear differences among our focal taxa in terms of their use of undercrossing structures. In our study, almost all of the deer passage events occurred at the two large underpasses at either end of the wildlife exclusion fence (Table 2). These findings are consistent with previous studies that have concluded that deer rarely use small confined undercrossings (Donaldson 2009, Mastro 2008). Even at the large, open, and heavily utilized Santa Margarita Creek channel, we obtained photo sequences that suggested that the deer were hesitant to cross under the highway, perhaps due to the noise of passing vehicles that the deer could not see. Deer rarely used culverts, even those that were fairly large and well-lit. Because our cameras were usually located in the middle of the culverts, we were unable to determine the extent that deer approached culverts but declined to enter. However, at one of our sites (Woods Winery; see Table 2), we mounted the camera at the far entrance to minimize the likelihood of human disturbance, and we obtained several photo sequences of deer approaching the culvert entrance and even jumping over a pipe-rail livestock gate but then turning away rather than passing through the 6-ft wide, 8-ft high concrete box culvert. These data provide further evidence that deer are reluctant to pass through even relatively large culverts, even in the absence of use by mountain lions, their primary predator. A notable exception to this pattern was the occasional use of an 8-ft wide, 4-ft high concrete box culvert near the center of the wildlife exclusion fence zone. The deer passage events at this culvert may have been the same individual deer (see Perrine 2015 for more detail). As noted above for the jumpouts, the behavior of individual deer near the highway may be best documented via GPS telemetry.

In contrast to deer, black bears used a wide variety of culverts, ranging from 4 ft by 4 ft concrete box culverts to large open underpasses. The most striking pattern for bear was the sites that they did not use (Table 2). Surprisingly, bear were never detected by any of the three cameras in the Santa Margarita Creek channel from 2012-2014. The wildlife trail along the north bank of the creek was also monitored for six weeks in 2009-2010 during a previous wildlife study (Perrine and Snyder 2011), and no bear were

Table 2. Total activity per survey night for our four focal species. BCAT = bobcat, BEAR = black bear, DEER = mule deer, LION = mountain lion. *At "Woods Winery," deer were detected at the entrance but did not actually pass through the culvert. For comparison, a use rate of 0.003 animals per survey day equates to 1 detection/year (1/365), 0.033 would be 1 detection/month (1/30), and 0.143 would be 1 detection/week (1/7).

Site	DEER	BEAR	LION	BCAT
Santa Margarita Creek				
North bank (C11)	1.355	--	0.005	0.044
Center channel (C12)	0.576	--	0.005	0.016
South bank (C13)	0.301	--	--	0.016
Railroad flyover				
North side (C15)	0.736	0.012	--	0.086
South side (C16)	0.374	0.016	--	0.033
Tassajara Creek (C05)	--	0.020	--	0.010
N10.0 (C08)	0.004	--	--	0.006
N 8.5 (C06)	--	--	--	0.415
N 9.1 (C07)	--	--	--	0.145
Woods Winery (C01)	0.031*	0.003	--	0.111
N 3.1 (C02)	--	0.018	0.023	0.445
Water District (C14)	0.005	0.022	0.004	0.048
Highway 58N (C10)	--	0.023	--	--
Highway 58S (C09)	--	0.025	--	0.070

detected then either; however, additional sampling at this site resulted in bear detections in May, July, and August 2011. At least two black bear roadkills have occurred within 1 mi of this underpass since 2012, indicating that bears do occur in the area and may be crossing the highway itself rather than using the creek channel. Whether other bears are crossing successfully remains unknown.

Also surprisingly, bear were never detected at any of the three drive-through culverts north of the wildlife exclusion fence. Two of these culverts (N8.5 and N10.0) were also monitored for portions of 2009-2010, and bear were also not detected. These results strongly suggest that these culverts, although larger and better-lit than some of the culverts in the wildlife fence zone, do not provide much connectivity for bears. Perhaps in this area, where there is no wildlife fence and little concrete median barrier, bears cross the highway at grade, or perhaps bears simply do not use this area very much. The habitat here is predominantly oak woodland and cattle pasture, so it has less shrub cover than the rest of the study area to the south, but landscape models identified the area near these drive-through culverts as potentially high-connectivity habitat for bears (Thorne and Huber 2011).

Mountain lion was the most highly restricted of our focal species, detected at only four sites in this study. Use was highest at a 10-ft wide circular culvert just south of the wildlife exclusion fence zone, but most of the activity may have been due to repeated passage of a single individual. Within the wildlife exclusion fence zone, mountain lion were detected only twice during the two-year study, and both at the same culvert (which happened to be the same culvert that the deer used, as mentioned above). Surprisingly, the use of the large, open Santa Margarita Creek channel was no higher, and lions were never detected at the three drive-through culverts north of the wildlife exclusion fence zone (although they have since been detected there, and at the railroad undercrossing at the south end of the exclusion fence, in subsequent monitoring).

Bobcats were detected at 13 of the 14 culverts and underpasses. The sites with the highest bobcat passage rates were outside of the wildlife exclusion fence zone, including several of the large drive-through culverts that the larger mammals rarely used. Passage rates within the wildlife fence zone were fairly low compared with these sites, even at the large open underpasses at the railroad crossing and the Santa Margarita Creek channel.

Undercrossings: Next Steps

With our expanded 5-year dataset, we plan to develop a series of models to quantify how the culvert structure and context affect use by our focal species. Culvert structure includes the length, width, and height of each undercrossing (quantitative variables), and whether its exit can be seen from the entrance (binary variable). Culvert structure can be characterized via an "openness" index: (height*width)/length (Cain et al. 2003); larger openness values indicate wider, shorter culvert; low values indicate long, narrow culvert.

Yanes et al. (1995) and Mastro et al. (2008) found that deer prefer large open undercrossings over narrow and dark passages, and Grilo et al. (2008) found that carnivores were less likely to use smaller culverts. The culvert context includes characteristics of the surrounding habitat, such as habitat type and amount of vegetative cover near the culvert entrances. In addition, the permeability of the surrounding landscape may also affect the extent of wildlife use at specific culverts. To control for landscape effects, we will use GIS to extract the modeled landscape movement resistance values for each focal species (Thorne and Huber 2011) from the areas near each culvert's entrances. Lastly, we intend to include human activity at each culvert as a covariate. Clevenger and Waltho (2000) found human activity levels to be the most important predictor of carnivore use (negative correlation) and Clevenger and Barrueto (2014) found human activity had a slight negative impact on deer and mountain lion use of crossing structures, but no impact on bear use. We will quantify human activity level as for focal species; namely, as the number of detections per survey night. Because our data is count-based, and there may be a significant number of months where we did not detect a particular focal species, we will use a zero-inflated Poisson generalized regression model to determine which of the structural and context variables best explains the activity of our focal species. Our findings will contribute to designing and building more effective wildlife crossing structures, to the benefit of wildlife and humans alike.

LITERATURE CITED

Bissonette, J., and M. Hammer. 2000. Effectiveness of earthen return ramps in reducing big game highway mortality in Utah. UTCFWRU Report Series 2000:1-29.

Cain, A. T., V. R. Tuovila, D. G. Hewett, and M. E. Tewes. 2003. Effects of a highway and mitigation projects on bobcats in southern Texas. Biological Conservation 114:189-197.

Clevenger, A. P., and M. Barrueto. 2014. Trans-Canada highway wildlife and monitoring research, final report: Part B-Research. Prepared for Parks Canada Agency, Radium Hot Springs, British Columbia, Canada.

Clevenger, A. P., B. Chruszcz, and K. E. Gunson. 2001. Highway mitigation fencing reduces wildlife-vehicle collisions. Wildlife Society Bulletin 29:646-653.

Clevenger, A. P., and M. P. Huijser. 2011. Wildlife crossing structure handbook design and evaluation in North America. Report to the Federal Highway Administration, Washington, DC. No. FHWA-CFL/TD-11-003.

Clevenger, A. P., and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14:47-56.

Clevenger, A. P., and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. Biological Conservation 121:453-464.

Crooks, K. R. 2002. Relative sensitivities of mammalian carnivores to habitat fragmentation. Conservation Biology 16:488-502.

Donaldson, B., Y. Kweon, and L. N. Lloyd. 2015. An evaluation of roadside activity and behavior of deer and black bear to determine mitigation strategies for animal-vehicle collisions. No. FHWA/VTRC 16-R4. Virginia Transportation Research Council. Charlottesville, VA.

Forman, R. T., and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29:207-231.

Gagnon, J. W., C. D. Loberger, S. C. Sprague, M. Priest, K. Ogren, S. Boe, E. Kombe, and R. E. Schweinsburg. 2013. Evaluation of desert bighorn sheep overpasses along US Highway 93 in Arizona, USA. Proceedings of the 2013 International Conference on Ecology and Transportation.

Garbutt, H. 2009. Wildlife-vehicle mitigation on Northeastern Ontario highways. Ontario Ministry of Transportation, Northeast Region, Ontario, Canada.

Grilo, C., J. A. Bissonette, and M. Santos-Reis. 2008. Response of carnivores to existing highway culverts and underpasses: implications for road planning and mitigation. Biodiversity and Conservation 17:1685-1699.

Huijser, M. P., J. W. Duffield, A. P. Clevenger, R. J. Ament, and P. T. McGowen. 2009. Cost-benefit analyses of mitigation measures aimed at reducing collisions with large ungulates in the United States and Canada: a decision support tool. Ecology and Society 14.2 Article 15.

Huijser, M. P., A. V. Kociolek, T. D. H. Allen, P. McGowen, P. C. Cramer, and M. Venner. 2015. Construction guidelines for wildlife fencing and associated escape and lateral access control measures. NCHRP 25-25(84).

Hurlbert, S. H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54:187-211.

Jennings, M. K. 2013. Landscape dynamics in Southern California: understanding mammalian carnivore response to fire and human development. Ph.D. dissertation. University of California, Davis, and San Diego State University.

Kramer, D. W., T. J. Prebyl, J. H. Stickles, D. A. Osborn, B. J. Irwin, N. P. Nibbelink, R. J. Warren, and K. V. Miller. 2016. Using GPS telemetry to determine roadways most susceptible to deer-vehicle collisions. Journal of the Southeastern Association of Fish and Wildlife Agencies 3:253-260.

Mastro, L. L., M. R. Conover, and S. N. Frey. 2008. Deer-vehicle collision prevention techniques. Human-Wildlife Conflicts 2:80-92.

Perrine J. D. and S. Snyder. 2011. Documenting wildlife distribution and activity along Highway 101 between San Luis Obispo and Atascadero. Contract 06A1337. California Department of Conservation, Sacramento, CA.

Perrine, J. D. 2015. Assessment of the wildlife-exclusion infrastructure in the Tassajara Creek Region of Highway 101 in San Luis Obispo County. California Department of Transportation, Sacramento, CA.

Poessel, S. A., C. L. Burdett, E. E. Boydston, L. M. Lyren, R. S. Alonso, R. N. Fisher, and K. R. Crooks. 2014. Roads influence movement and home ranges of a fragmentation-sensitive carnivore, the bobcat, in an urban landscape. Biological Conservation 180:224-232.

Riley, S. P., R. M. Sauvajot, T. K. Fuller, E. C. York, D. A. Kamradt, C. Bromley, and R. K. Wayne. 2003. Effects of urbanization and habitat fragmentation on bobcats and coyotes in southern California. Conservation Biology 17:566-576.

Riley, S. P., 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 159:165-173.

Rytwinski, T., K. Soanes, J. A. G. Jaeger, L. Fahrig, C. S. Findlay, J. Houlahan, R. van der Ree, and E. A. van der Grift. 2016. How effective is road mitigation at reducing roadkill? A meta-analysis. PLoS ONE 11(11): e0166941.

Siemers, J. L., K. R. Wilson, and S. Baruch-Mordo. 2015. Monitoring wildlife-vehicle collisions: analysis and cost-benefit of escape ramps for deer and elk on US Highway 550. Department of Fish, Wildlife, and Conservation. Colorado State University. Fort Collins, CO. Report No. CDOT-2015-05.

Siepel, N. R., J. D. Perrine, L. K. Schicker, and M. Robertson. 2013. Saving lives and training the next generation: State Route 101 wildlife corridor safety project. Proceedings of the 2013 International Conference on Ecology and Transport. (ICOET 2013).

Snyder, S. A. 2014. Examining the impacts of State Route 101 on wildlife using road kill surveys and remote cameras. MSc thesis, California Polytechnic State University, San Luis Obispo, CA.

Stickles, J. H., D. B. Stone, C. S. Evans, K. V. Miller, R. J. Warren, D. A. Osborn, and C. H. Killmaster. 2014. Using deer-vehicle collisions to map white-tailed deer breeding activity in Georgia. Journal of Southeastern Association of Fish and Wildlife Agencies 2:202-207.

Stull, D. W., W. D. Gulsby, J. A. Martin, G. J. D'Angelo, G. R. Gallagher, D. A. Osborn, R. J. Warren, and K. V. Miller. 2011. Comparison of fencing designs for excluding deer from roadways. Human-Wildlife Interactions 5:47-57.

Thorne, J. H., D. Cameron, and J. F. Quinn. 2006. A conservation design for the central coast of California and the evaluation of mountain lion as an umbrella species. Natural Areas Journal 26:137-148.

Thorne, J., and P. Huber. 2011. GIS modeling of landscape permeability for wildlife on the Highway 101 corridor between San Luis Obispo and Atascadero. Final project report to California Department of Transportation., Sacramento, CA.

Van Dyke F. G, R. H. Brocke, and H. G. Shaw. 1986. Use of road track counts as indices of mountain lion presence. Journal of Wildlife Management 50:102-109.

Yanes, M., J. M. Velasco, and F. Suarez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. Biological Conservation 71:217-222.