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Limited Wildlife Diversity at Highway Right-of-Way Crossings

Authors
Shilling, Fraser M.
Haverkamp, Paul
Santos, Maria
et al.

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Fraser M. Shilling
Paul Haverkamp
Maria Santos
Susan Ustin

Institute of Transportation Studies ◦ University of California, Davis
One Shields Avenue ◦ Davis, California 95616
PHONE (530) 752-6548 ◦ FAX (530) 752-6572
www.its.ucdavis.edu

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September 15, 2012

Fraser M. Shilling
Paul Haverkamp
Maria Santos
&
Susan Ustin

Road Ecology Center
Department of Environmental Science and Policy
&
Land Air and Water Resources

University of California, Davis
One Shields Ave., Davis, CA 95616

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PROBLEM

Understanding the impacts of transportation systems and related disturbances on wildlife movement is critical to mitigating these impacts. To understand these impacts, we investigated the occurrence and movement of terrestrial wildlife in the vicinity of a major highway in the Sierra Nevada, while controlling for other environmental and disturbance gradients. Road and highway systems impact the surrounding environment, changing flows, ecosystem processes, species relationships, landscape patterns, and other ecological attributes (Wheeler et al., 2005; Fahrig and Rytwinski, 2009).Roads and highways pose barriers to wildlife dispersal and migration through aversion effects ("habitat alienation", e.g., Mac et al., 1996), direct mortality from traffic (Madsen, 1996; Putman, 1997; Rubin et al., 1998), and traffic noise-induced effects (Reijnen et al., 1997; Gill et al., 1996). The combination of disturbed edge and physical barrier can reduce the effective area for species that depend on intact habitat in the interior of patches (Boarman and Sazaki, 2006) and that migrate among patches. Since roads are often accompanied by other development activities, there may be additional fragmentation effects beyond just the linear extent of the road (Theobald et al., 1997). Mitigation efforts for these fragmentation effects have been made in particular geographic locations by installing underpasses and overpasses intended for use by large mammals (e.g., Clevenger and Waltho, 2000). However, the effectiveness of these purpose-built structures, or existing drainage (culvert) and traffic structures for passing wildlife is seldom well-studied.

Fragmentation and connectivity

Fragmentation of wildlife habitat is one of the primary global threats to species diversity and cause of endangerment. Fragmentation is a spatially and temporally continuous process that leaves a legacy gradient across the landscape. However, the effects of fragmentation go beyond the simple measurement of physical properties, the use of a fragmenting infrastructure for human activities (e.g., traffic) is just as critical in understanding fragmentation effects on ecosystem functions (e.g., on wildlife movement; Putman, 1997; Riley, 2006). Fragmentation can be evaluated from a purely bio-physical or structural point of view – structural fragmentation, or as an emergent property of the physical disruption of landscapes – functional fragmentation, which may vary with spatial and temporal scale. Connectivity is the corollary to fragmentation and has been defined as follows: ''*the degree to which the landscape facilitates or impedes movement of organisms among patches*'' (Taylor et al. 1993; Tischendorf and Fahrig 2000). This definition leads to the question, "connectivity for whom?" which in turn leads to refining studies to understand spatial and temporal scales of organismal movement, the relationship between movement and disturbance gradients (e.g., traffic patterns), and the ecological importance of the movement and thus connectivity (e.g., to species persistence). Whilst structural fragmentation can be remediated through the implementation of connectors across the landscape, functional fragmentation can only be remediated by considering the presence *and* actual use of infrastructural elements by wildlife and their impacts on functional connections across a landscape.

Fragmentation by human actions is an evolving process. Low-intensity land-uses and low-density road systems may cause the least functional fragmentation, industrial and urban areas may provide the most. Fragmentation occurs as a continuous variable across our landscapes and is often analyzed on continuous scales (e.g., road density calculation in a grid; Trombulak and Frissell, 2000). At one end of the spectrum (e.g., un-roaded forested landscapes), natural-disturbance-mediated fragmentation may determine landscape patterns. Once landscapes are used for logging, rural sub-division, and grazing, there is intermediate to severe structural and functional fragmentation and artificial-disturbance-mediated fragmentation may dominate over natural-disturbance-mediated fragmentation. At the extreme end of the fragmentation spectrum (e.g., urban areas) there may be very little left of natural habitats to be connected, but other natural processes (e.g., water cycle) may be severely affected. When considering traffic effects on wildlife occurrence and movement, it is critical to measure and control for this continuous range of disturbance.

Temporal scale

Species life-history patterns affect their presence in any given portion of their home-range, landscape and ecosystem, as well as the land-use intensity through which they move. Further, as seasons progress throughout the year, different patterns of use and movement are also observed as organisms respond to seasonal changes in resource availability. These temporal scale effects can then modify the likelihood that road traffic can impact organismal movements (Broady and Pelton 1989; de Maynadier and Hunter 2000; Dyer et al. 2002; Ford and Fahrig 2008) and life history (Carr and Fahrig 2001). For example, during the reproductive season animals tend to have higher frequency of movements within their home-range, thus increasing their likelihood of being affected by traffic. On the other hand, during dispersal, individuals move longer distances, often crossing inhospitable terrain and obstacles, which if interrupted by road presence, can have major impacts at the population level, as population numbers decrease and overall populations fitness also decreases (Tanner and Perry 2007). Thus the temporal scale at which to assess road impacts on wildlife populations may also be a key element to understand impacts, and mitigation.

Predators have unique life-histories that reflect a 'functional-type' response to environmental quality and variability (Ferguson and Lariviere 2002); conservation plans designed using these species are predicted to encompass conservation goals for the entire landscape mosaic including human needs (for example see Ray 2005), and more cryptic species such as birds and butterflies (Sergio et al. 2005). Carnivore predation exerts top-down control of multiple trophic levels which in turn impacts species diversity, ecosystem processes, and ecosystem structuring (Crooks and Soule 1999; Terborgh et al. 1999; Terborgh et al. 2001). Carnivores are also a particularly valuable guild to study since they utilize the full gradient of habitats from natural to rural to urban (Davison et al. 2008; DeStefano and De Graaf 2003; Riley 2006). Despite the existing research being focused on large predators, medium-sized carnivores also structure ecosystems through trophic interactions, and their generalist strategy is likely to produce a larger effect than anticipated, only regulated by the presence of the larger species (Crooks and Soule 1999).

Wildlife movement

The movements of an organism can be categorized into three main types, movements within its home range, migration, and dispersal. Movements within a home range correspond to "the area traversed by an animal during its activities during a specified period of time" (Morrison and Hall 2002) and it corresponds to active procurement of food, mate or resting site. Migratory movements correspond to two-way seasonal movements between two disparate geographic locations performed one or more times during an animal life span. Dispersal corresponds to one-time movement performed, in general, by juveniles to establish their home-range in another area of suitable habitat away from their natal home-range. Movements often are dictated by a behavioral response to species requirements to maintain their basal metabolic rate and survival, and thus are expected to respond to internal and external stimuli and disturbance, such as fragmentation.

There are multiple ways to measure movements, from intrusive methods requiring the implantation of sensors of movement and blood pressure, through the use of telemetry and non-invasive survey methods, being the two most recent and often used. The selection of the best measurement method is highly dependent on the objective of the study, and the use of either telemetry or indirect methods has trade-offs. Telemetry has the great advantage of obtaining the precise location of the individual at equally spaced intervals of time. As technology advanced in the last decades, the development of miniaturized GPS collars for many wildlife species has improved our knowledge of species responses to disturbance as that caused by roads (for examples see Dodd et al. 2007; Gagnon et al.

2007), as well as allowing us to know how organisms are using roads and at what frequency they cross them. Alternatively, if the questions are to know the effect of road on a vertebrate assemblage or if culverts and other roads impact mitigation structures are being used by wildlife, non-invasive methods have been used, such as recording road kills (Grilo et al. 2009; Bellis 2008) and using indirect detection methods as remote-triggered infrared cameras, scent stations (Grilo et al. 2008), and/or track plates.

Wildlife movement in a developed landscape leads to conflict. In the case of roads, this conflict can be fatal to both driver and animal. Recently, road ecologists and wildlife biologists have attempted to predict where conflict may occur in order to reduce the effects. Others have attempted to relate successful animal crossings (instead of road casualties) with environmental and traffic variables to predict road-crossing probabilities (Dussault et al. 2007; Alexander 2008). For instance, Dussault et al. (2007) used radio telemetry collars on moose to develop a spatial model in order to predict highway-crossing probabilities and, therefore, infer the risk of moose-vehicle collisions. Alexander (2008) surveyed snow tracks of four species of carnivores (cougar *Puma concolor*, wolf *Canis lupus*, Canadian lynx *Lynx canadensis*, and pine marten *Martes americana*) to identify wildlife crossings and to relate the crossings with environmental variables. In many cases, models that try to relate road-kill data or animal crossings with environmental and traffic variables use generic variables that are not species-specific. To address this issue, Roger and Ramp (2009) incorporated variables that describe the species' habitat use into the model. They found that using habitat-specific variables greatly improved the predictive ability of the road-kill model.

Wildlife-Vehicle Collisions

Traffic-caused wildlife mortality (road-kill) is a result of highway development. All terrestrial vertebrate and invertebrate taxa (including birds and flying insects) may be killed by vehicles moving along transportation corridors. Individual roads, railways, and highways may exact significant tolls on wildlife populations. This can result in local extirpation, abandonment of important habitats and migration corridors, and local population sinks. Certain taxa must move regularly between two adjacent areas separated by roadways. In species with low mobility, such as some reptiles and amphibians, casualties tend to occur during the spring season when animals are migrating to and from their breeding ponds (Seiler, 2002; Aresco, 2005; Beaudry et al. 2008). Wildlife collisions not only can decrease numbers within a population, but can prevent interactions of species within the community and decrease genetic connectivity (Epps et al., 2005; Riley, 2006; Strasburg, 2006). Species behavior can also cause a barrier effect through road avoidance (McLellan and Shackleton, 1988; Lovallo and Anderson, 1996; Whittington et al., 2004; Alexander et al., 2005; Blanco et al., 2005; Jaeger et al., 2005). Wildlife-vehicle collisions can also be dangerous for the human driver and in the US, results in millions of dollars per year in property damage, and thousands of fatalities and injuries.

KEY FINDINGS

Wildlife-vehicle collisions are economic, safety, and ecological costs of transportation systems. Although understanding of the reasons that collisions occur is increasing, for most road and highway systems in California and elsewhere, the proximate causes of both collisions and avoidance of collisions are unknown. Thus there is inadequate understanding of both contributing factors and impacts to wildlife of successful and unsuccessful interactions with highways. By identifying critical wildlife movement needs in relation to transportation systems, transportation and other infrastructure, planners often hope to improve and mitigate (avoid, minimize, or compensate for) wildlife impacts. We hypothesize that ground-dwelling vertebrate species are able to occupy and move through the highway right-of-way, making use of highway under and over crossings to successfully avoid collisions. To test this hypothesis, we measured wildlife occupancy of the highway rights-of-way and opportunistic use of highway under-crossings. We investigated the effects of disturbance gradients on mammal movement and occurrence.

1) We found that diversity was relatively low in the highway right-of-way and at highway under-crossings. Across 6 highway under-crossings, only 8 of 38 possible species were observed moving through these crossings from one side of the highway right-of-way to the other. This has important implications for understanding ecological impacts of roads and mitigation efforts to reduce impacts.
2) We found that alpha diversity (Simpson's Index of Diversity) at highway crossings ranged widely for wildlife near street under and over-crossings, but was not related to nearby land development.
3) Wildlife use of existing under-crossing structures was inversely proportional to the presence of humans and frequency of human use of the same structures. This has important implications for effectiveness of existing structures and purpose-built "wildlife crossings" to provide for wildlife movement.

METHODOLOGY

Landscape and Traffic Patterns

The study area for this project was the interstate 80 ("I-80") transportation corridor in the lower and mid-foothills of the Sierra Nevada, between the towns of Auburn and Alta. The predominant natural land-cover types are: oak woodland, mixed oak woodland/conifer, and conifer-dominated. Development ranged from un-developed to rural residential housing. The interstate is a 4-lane highway with a concrete median barrier along most of the length through the study area. There are an unknown number of culverts and bridge underpasses in this stretch of highway. Despite repeated attempts to access these data, Caltrans would not share them with the authors. Therefore no finding can be made about how representative the study culverts and bridge under-crossings are for this highway. There are 20 street over-crossings and 13 street under-crossings and 7 railroad under-crossings in the study highway. Ten of the street over-crossings, 10 of the street under-crossings, and 4 of the railroad under-crossings were investigated for wildlife occupancy using a combination of track plates and remote cameras.

To measure the gradient of structural fragmentation in this corridor, we analyzed urbanized development within 0.5 and 1 km radii of each track plate and remote camera. Development and other land cover was derived from the national Land Cover Dataset (NLCD, 2006) by buffering a point representing each crossing structure by 0.5 and 1 km (radius) circles and tabulating the total area of each cover type in the NLCD. Similar cover types (e.g., various types of forest cover) were aggregated to simplified categories.

Wildlife Occurrence and Movement: Track Plates

To assess patterns of occurrence of wildlife around roads, we used baited track-plates and remote, movement-triggered cameras. The track plates had printer toner at one end, followed by contact shelving-paper, then bait. Track-plates were placed at 20 street-bridges crossing over or under the highway at intervals of 0, 250, and 500 meters from the crossing (Figure 1). Track plates at the crossing (0 m) were uncovered, track plates at 250 and 500 m were covered with an inverted-V shaped structure. Plates were deployed for 12 consecutive days at each site during the Summer (2010) and again in the Fall of the same year. Plates were visited every other day over 12 consecutive days (6 visits) to check for detections and to renew bait (canned tuna). Tracks left on the contact paper were compared to the footprint metrics in the available literature (Zielinski and Truex 1995; Taylor and Raphael 1988).

Wildlife Occurrence and Movement: Remote Cameras

To assess movement of animals through under-crossing structures, free-standing, movement-triggered cameras were placed at 6 culverts and bridges crossing the interstate (Figure 1). Both Cuddeback (model) and Bushnell Trophy Cam II were used. Cuddeback cameras were set to high sensitivity and used at locations with short detection distances, such as the opening of culverts. Bushnell cameras were also set to high sensitivity and used at detection distances of up to 10 meters. Detection distances are defined here to mean the distance between the camera and a solid surface, such as a wall, the ground, or dense vegetation. Cameras were primarily used in still mode. Video mode was used to confirm that entry into a structure was likely to be a crossing event. Cuddeback cameras were checked (batteries and SD cards changed) every month, Bushnell cameras were checked every 1-2 months. Cameras were deployed for up to 12 months at each monitoring site.

Species Diversity

A common measure of alpha diversity (diversity of species within an ecosystem) is the Simpson's Diversity Index (Simpson, 1949), which is expressed as follows:

$$D = \frac{\sum_{i=1}^{S} n_i(n_i - 1)}{N(N-1)}$$

Where: ni = The number of individuals in each species; the abundance of each species. S = The number of species. Also called species richness. N= The total number of all individuals. pi = The relative abundance of each species, calculated as the proportion of individuals of a given species to the total number of individuals in the community: ni/N.

This Index takes into account the number of individual animals for each species observed. Because this formula results in low values for heterogeneous communities and high values for homogeneous communities, an alternative expression of the Index is often used, where D is subtracted from 1 to give D', which is commonly called the Simpsons Index of Diversity. In the current study, the number of individuals of each species or species group was counted for both track plate and camera observations. There was no way to distinguish between individuals and some individuals may be counted twice using track plates and cameras. In addition, certain tracks could only be classified to the genus (Microtus and

Peromyscus) or large group (rodent, bird/lizard) level. These were included in the Index calculation, but may include several species within each group. Thus, the Index is an approximate indication of alpha diversity at crossing structures.

RESULTS

This project included estimation of animal occurrence near and using structures (e.g., culverts, street, and RR crossing structures) to cross the Interstate-80 right of way. A combination of track plates near over-crossings and remote cameras at under-crossings was used to index wildlife occurrence and crossings.

Tracking Small and Medium Animals

At least 6 species and 2 genuses of mammals occurred in the vegetated right-of-way near street over-crossings. In addition, unidentified rodents, birds, and lizards occurred and attempted to scavenge the bait from the track plate devices. Of the 8 groups, the Mouse (Peromyscus sp.), California ground squirrel (Spermophilus beecheyi), and unknown rodents accounted for greater than 80% of observed tracks (Table 1). There are 5 native Peromyscus species and 3 native Microtus species that occur in the Sierra Nevada (Graber, 1996) and for this study, we did not attempt to discriminate among the species within each genus.

Table 1. Summary of species and species groups observed at street over-crossings.

Species/ group	Skunk	Raccoon	Virginia opossum	Fox	California ground squirrel	Microtus spp.	Peromyscus sp.	Woodrat	Rodent	Bird/ lizard
N	7	4	2	5	70	2	279	16	32	8
%	1.5	0.9	0.4	1.1	15.1	0.4	60.3	3.5	6.9	1.7

Species diversity (Simpson’s Index of Diversity) ranged from 0 to 0.80 across the 20 street over-crossings studied along the interstate, and averaged 0.54 across all crossings (Table 2). There was no relationship between Simpson’s Index of Diversity or total number of tracks and any of the major land cover types within 1 km (Table 2) and 0.5 km (Table 3) distances from the crossings.

Table 2 Land cover within 1 km of each street crossing with track plates. Data are from the National Land Cover Dataset (2006).

Crossing #	Tracks observed (#)	Simpson's Index of Diversity	Developed lands (%)	Forested (%)	Grass/shrub (%)	Herbaceous wetland (%)
116	21	0.61	33.3	14.7	2.0	0
122	12	0.74	17.2	23.8	9.0	0
123	14	0.59	11.8	33.2	5.0	0
124	35	0	8.9	33.7	7.4	0
125	22	0.09	15.6	31.6	2.4	0
128	22	0.54	12.5	32.9	4.6	0
131	12	0.17	12.2	35.8	1.9	0
140	10	0.78	14.7	28.6	6.7	0
145	6	0.80	6.0	43.1	0.9	0
146	16	0.59	8.7	39.6	1.7	0
148	17	0.32	8.8	34.1	7.1	0
148A	15	0.34	11.1	35.2	3.1	0
150	13	0.63	6.8	41.1	2.1	0
155	14	0.76	3.2	39.3	7.5	0
156	57	0.59	5.9	37.2	6.8	0
158	22	0.48	2.9	30.9	15.2	0
158A	12	0.41	6.9	34.3	8.4	0.9
164	39	0.59	7.7	37.2	4.7	0.4
165	34	0.43	5.5	20.7	23.5	0
151	32	0.49	7.6	28.6	13.8	0

Table 3 Land cover within 0.5 km of each street crossing with track plates. Data are from the National Land Cover Dataset (2006).

Crossing #	Tracks observed (#)	Simpson's Index of Diversity	Developed lands (%)	Forested (%)	Grass/shrub (%)	Herbaceous wetland (%)
116	21	0.61	71.8	20.3	7.9	0
122	12	0.74	46.2	33.9	19.9	0
123	14	0.59	44.7	44.5	10.9	0
124	35	0	30.9	64.8	4.4	0
125	22	0.09	48.4	45.9	5.7	0
128	22	0.54	41.3	47.1	11.4	0
131	12	0.17	39.7	57.3	3.0	0
140	10	0.78	43.0	35.8	21.1	0
145	6	0.80	20.9	76.8	2.3	0
146	16	0.59	32.4	65.8	1.8	0
148	17	0.32	35.4	53.4	11.1	0
148A	15	0.34	34.7	53.3	5.1	0
150	13	0.63	25.7	70.3	4.0	0
155	14	0.76	12.3	69.6	18.1	0
156	57	0.59	23.0	68.7	8.4	0
158	22	0.48	11.7	42.4	45.8	0
158A	12	0.41	20.4	58.9	19.6	1.0
164	39	0.59	24.6	69.3	6.1	0
165	34	0.43	20.6	48.4	31.0	0
151	32	0.49	31.5	51.7	16.9	0

Deer Movement

The ability of deer to move above or below the right-of-way using purpose-built and ad hoc crossing structures is a critical conservation and safety function. In the Sierra Nevada foothills, many deer are thought to be resident and no longer seasonally migrate up and down-slope. At one crossing, Weimar Cross Rd RR under-crossing, 312 deer were detected during 310 days of camera monitoring. Few deer moved through the structure in the Summer, but the number crossing increased rapidly during the Fall, the rutting season and again in the Winter (Figure 1). This increase in crossing events suggests that, during these seasons, there is either more movement per animal, or more animals, or both.

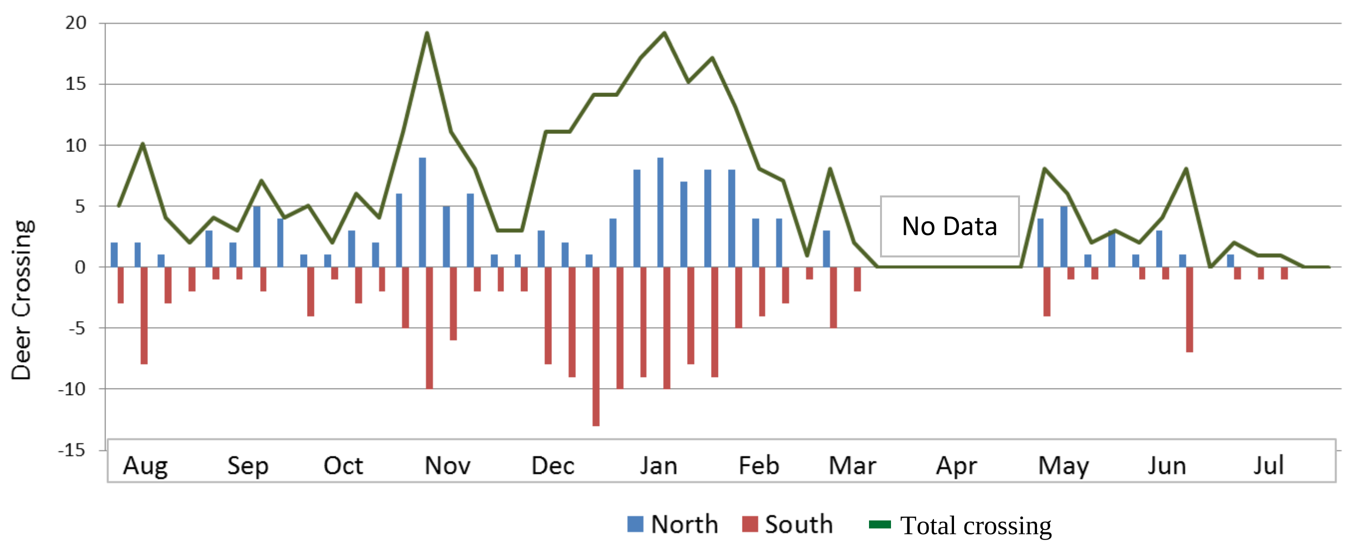

Figure 1 Weekly deer crossing at one structure in north or south direction and total number crossing.

Structure-Specific Crossing Activity

There was no relationship between the number of wildlife species using structures and the daily number of people using these structures (Table 4). However, there was a strong relationship between the daily number of wildlife individuals of any species using the structure and the daily number of people using the same structure (Figure 2). In the absence of people, 1-2 individual wild animals used the structures per day. Once there was on average >0.5 people/day, the number of individual animals was consistently low to at least 2.7 people/day.

Table 4 Number of wildlife species and number of people using crossing structures under the interstate.

Structure location/type	Number of wildlife species	Number of people/day
Western ravine Auburn culvert	4	0
Eastern ravine Auburn culvert	6	0
Bowman RR UC west	5	2.67
Bowman RR UC east	3	0.33
Paoli Rd RR UC	4	0.45
Weimar Rd RR UC	6	0.08

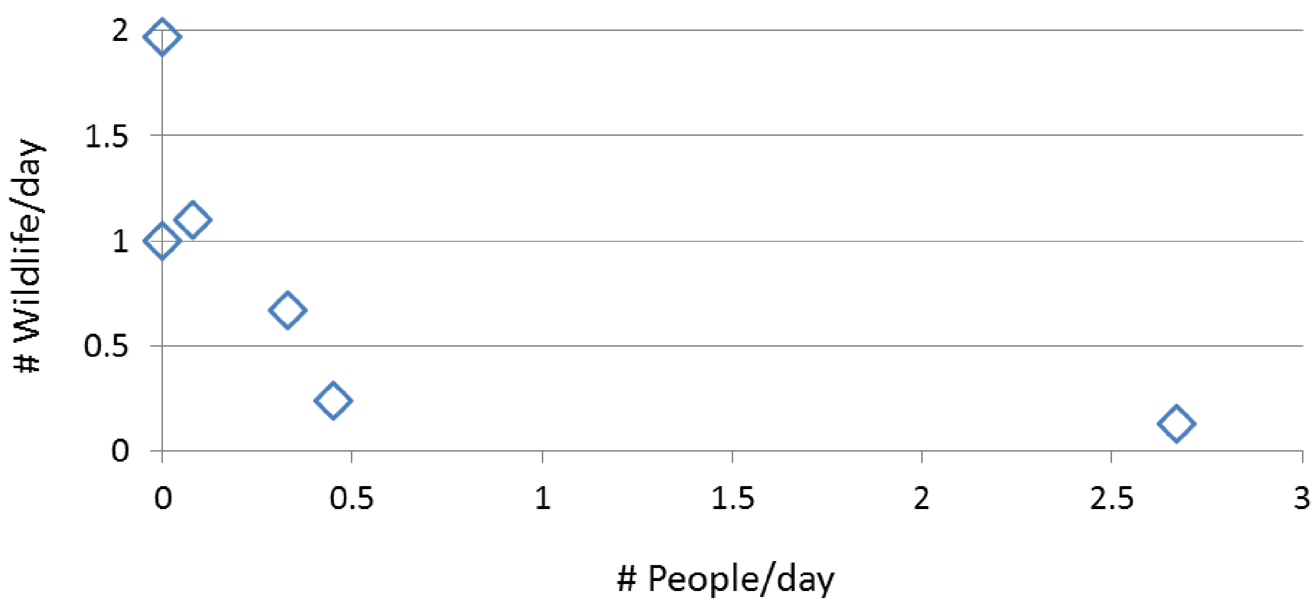

Figure 2 Relationship between 3 of individual wildlife using a crossing and number of people using the same crossing.

CONCLUSIONS

Wildlife use existing infrastructure to successfully cross the interstate right-of-way. Use of the structures depended on frequency of use of the same structures by humans. This means that permeability of the state highway system could potentially be improved simply by protecting crossings from frequent human use. Although existing structures were useful in improving connectivity of the landscape, fewer than 20% of terrestrial vertebrate species in the eco-region were detected at under-crossings and fewer than half of terrestrial vertebrate species in the eco-region were detected with track plates or remote cameras, despite 480 days of track plate exposure (20 crossings) and 850 days of camera detection (6 locations). Very common, disturbance tolerant species/genuses (Raccoon, Virginia opossum, Mule deer, Gray fox, Vole, Mouse) dominated the combination of observations at track plates and remote cameras, regardless of the degree of development of the adjacent landscape. This suggests that rare, cryptic, and disturbance-intolerant species may not approach or use crossing structures. In order for wildlife crossings under or over busy highways to be successful, they may need to incorporate methods to reduce the apparent disturbance of the highway environment, for example through visual and noise abatement strategies. These results also suggest that individual interstates and highways can pose significant and essentially impermeable barriers to movement of most wildlife species, threatening them with isolation and increased risk of local and regional extinction.

RECOMMENDATIONS

1) More comprehensively and continuously monitor wildlife use across a range of highway and interstates and types.
2) Measure the effectiveness of existing structures to pass wildlife in order to determine gaps in this capacity for the California state highway system
3) Develop an infrastructure for monitoring wildlife movement through the highway rights-of-way similar to the traffic-cam system.

CITATIONS

Alexander, S.M., N.M. Waters, and P.C. Paquet. 2005. Traffic volume and highway permeability for a mammalian community in the Canadian Rocky Mountains. The Canadian Geographer, 49(4): 321-331.

Alexander, S.M. 2008. Snow-tracking and GIS: using multiple species-environment models to determine optimal wildlife crossing sites and evaluate highway mitigation plans on the Trans-Canada Highway. The Canadian Geographer, 52(2): 169-187.

Aresco, M.J.. 2005. Mitigation measures to reduce highway mortality of turtles and other herpetofauna at a north Florida lake. Journal of Wildlife Management, 69(2): 549-560.

Beaudry, F., P.G. deMaynadier, and M.L. Hunter Jr. 2008. Identifying road mortality threat at multiple spatial scales for semi-aquatic turtles. Biological Conservation, 141: 2550-2563.

M.A. Bellis 2008. Evaluating the effectiveness of wildlife Crossing structures in southern Vermont. Thesis to The University of Massachusetts.

Blanco, J.C., Y. Cortes, and E. Virgos. 2005. Wolf response to two kinds of barriers in an agricultural habitat in Spain. Canadian Journal of Zoology, 83: 312-323.

Boarman, W. I., and M. Sazaki. 2006. A highway's road-effect zone for desert tortoises (Gopherus agassizii). Journal of Arid Environments 65:94–101.

Bolliger, J., H. Lischke, and D.G. Green. 2005. Simulating the spatial and temporal dynamics of landscapes using generic and complex models. Ecological Complexity, 2(2): 107-116.

Brody, A. J., and M. R. Pelton. 1989. Effects of roads on black bear movements in western North Carolina. Wildlife Society Bulletin 17:5–10.

Carr, L. W., and L. Fahrig. 2001. Effect of road traffic on two amphibian species of differing vagility. Conservation Biology 15:1071–1078.

Clevenger, A.P. and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14(1): 47-56.

Crooks, K.R. and M.E. Soule, Mesopredator release and avifaunal extinctions in a fragmented system. Nature, 1999. 400: p. 563-566.

Davison, J., et al., 2008. Urban badger setts: characteristics, patterns of use and management implications. Journal of Zoology, London, 275(2): 190-200.

de Maynadier, P. G., and M. L. Hunter. 2000. Road effects on amphibian movements in a forested landscape. Natural Areas Journal 20:56–65.

DeStefano, S. and R.M. DeGraaf, Exploring the ecology of suburban wildlife. Frontiers in Ecology and the Environment, 2003. 1(2): p. 95-101.

Dodd, N.L., J.W. Gagnon, S. Boe, R.E. Schweinsburg. 2007. Assessment of elk highway permeability by using Global Positioning System telemetry The Journal of wildlife management 71(4): 1107-1117

Dussault, C., J-P. Ouellet, C. Laurian, R. Courtois, M. Poulin, and L. Breton. 2006. Moose movement rates along highways and crossing probability models. Journal of Wildlife Management, 71(7): 2338-2345.

Dyer, S. J., J. P. O'Neill, S. M. Wasel, and S. Boutin. 2002. Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern Alberta. Canadian Journal of Zoology 80:839–845.

Epps, C.W., J.D. Wehausen, V.C. Bleich, S.G. Torres, and J.S. Brashares. 2007. Optimizing dispersal and corridor models using landscape genetics. Journal of Applied Ecology, 44: 714-724.

Fahrig, L., and T. Rytwinski. 2009. Effects of roads on animal abundance: an empirical review and synthesis. Ecology and Society 14(1): 21. [online] URL: http://www.ecologyandsociety.org/vol14/iss1/art21/

Ferguson, S.H. and S. Lariviere, 2002. Can comparing life-histories help conserve carnivores? Animal Conservation, 2002(5): 1-12.

Ford, A. T. and L. Fahrig. 2008. Movement patterns of eastern chipmunks (Tamias striatus) near roads. Journal of Mammalogy 89:895–903.

Gagnon, J.W., T.C. Theimer, N.L. Dodd, R.E. Boe. 2007. Traffic volume alters elk distribution and highway crossings in Arizona. Journal of Wildlife Management,

Gibbs, J.P. and W.G. Shriver. 2002. Estimating the effects of road mortality on turtle populations. Conservation Biology, 16(6): 1647-1652.

Gill, J.A., W.J. Sutherland, and A.R.Watkinson. 1996. A method to quantify the effects of human disturbance on animal populations. Journal of Applied Ecology 33(4): 786-792.

Hels, T. and E. Buchwald. The effect of road kills on amphibian populations. Biological Conservation, 99: 331-340.

C. Grilo, 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 Conservation17: 1685-1699.

C. Grilo, J. A. Bissonette and M. Santos-Reis. 2009. Spatio-temporal patterns in Mediterranean carnivore road casualties: consequences for mitigation. Biological Conservation 142(2):301-313.

Jaeger, J.A.G. and 9 others. 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. Ecological Modelling, 185: 329-348.

Jaarsma, C.F., F. van Langevelde, H. Botma. 2006. Flattened fauna and mitigation: traffic victims related to road, traffic, vehicle, and species characteristics. Transportation Research D 11(4): 264–276.

Jaarsma, C.F., F. van Langevelde, J.M. Baveco, M. van Eupen, and J. Arisz. 2007. Model for rural transportation planning considering simulating mobility and traffic kills in the badger Meles meles. Ecological Informatics, 2: 73-82.

Long, R.A., et al., Noninvasive survey methods for carnivores. 2008: Island Press. 385

Lovallo, M.J. and E.M. Anderson. 1996. Bobcat movements and home ranges relative to roads in Wisconsin. Wildlife Society Bulletin, 24(1): 71-76.

Mac, R.D., J.S. Waller, T.L. Manley, L.J. Lyon, and H. Zuuring. 1996. Relationships among grizzly bears, roads and habitat in the Swan Mountains, Montana. Journal of Applied Ecology 33(6):1395-1404.

MacKenzie, D.I., et al. 2003a. Estimating site occupancy rates when detection probabilities are less that one. Ecology, 83(8): p. 2248-2255.

MacKenzie, D.I., et al., 2003b. Occupancy estimation and modeling. London: Academic Press.

Madsen, A.B. 1996. Otter Lutra lutra mortality in relation to traffic, and experience with newly established fauna passages at existing road bridges. Lutra 39(2): 76-88.

McLellan, B.N. and D.M. Shackleton. 1988. Grizzly bears and resource-extraction industries: effects of roads on behavior, habitat use, and demography. The Journal of Applied Ecology, 25(2): 451-460.

Morrison. M.L. and L.S. Hall 2002. Standard Terminology: towards a common language to advance ecological understanding and application. In Scott, J.M., P.J. Heglund, M. Morrisson et al. Predicting Species Occurrence: Issues of Accuracy and Scale. Island Press, Covel CA: 43-52.

Pichancourt, J-B., F. Burel, and P. Auger. 2006. Assessing the effect of habitat fragmentation on population dynamics: an implicit modeling approach. Ecological Modelling, 192(3-4): 543-556.

Putman, R. J. 1997. Deer and road traffic accidents: Options for management. Journal of Environmental Management 51(1): 43-57.

Ray, J. 2005. Large Carnivorous Animals as Tools for Conserving Biodiversity: Assumptions and Uncertainties, in Large Carnivores and the Conservation of Biodiversity, J. Ray, et al., Editors. Island Press.

Reijnen, R., R. Foppen, and G. Veenbaas. 1997. Disturbance by traffic of breeding birds: Evaluation of the effect and considerations in planning and managing road corridors. Biodiversity and Conservation 6(4): 567-581.

Riley, S.P.D. 2006. Spatial ecology of bobcats and gray foxes in urban and rural zones of a national park. Journal of Wildlife Management, 70(5): 1425-1435.

Roger, E. and D. Ramp. 2009. Incorporating habitat use in models of fauna fatalities on roads. Diversity and Distributions, 15: 222-231.

Rubin, E.S., Boyce, W.M., Jorgensen, M.C., Torres, S.G., Hayes, C.L., O'Brien, C.S., Jessup, D.A. 1998. Distribution and abundance of bighorn sheep in the Peninsular Ranges, California. Wildlife Society Bulletin 26(3): 539-551.

Seiler, A. 2002. Effects of Infrastructure on Nature. In: Trocmé, M.; Cahill, S.; De Vries, J.G.; Farrall, H.;Folkeson, L.; Fry, G.; Hicks, C. and Peymen, J. (Eds.) COST 341 - Habitat Fragmentation due to transportation infrastructure: The European Review, pp. 31-50. Office for Official Publications of the European Communities, Luxembourg.

Sergio, F., I. Newton, and L. Marchesi, 2005. Top predators and biodiversity. Nature, 436: p. 192.

Simpson, E. H. (1949) Measurement of diversity. Nature, 163, 688.

Smith, J.E. and G.O. Batzli. 2006. Dispersal and mortality of prairie voles (Microtus ochrogaster) in fragmented landscapes: a field experiment. Oikos, 112(1): 209-217.

Stephens, S.E., J.J. Rotella, M.S. Lindberg, M.L. Taper, and J.K. Ringelman. 2005. Duck nest survival in the Missouri Coteau of North Dakota: Landscape effects at multiple spatial scales. Ecological Applications, 15(6): 2137-2149.

Strasburg, J.L. 2006. Roads and genetic connectivity. Nature, 440: 875-876.

Tanner, D., and J. Perry. 2007. Road effects on abundance and fitness of Galápagos lava lizards (Microlophus albemarlensis). Journal of Environmental Management 85:270–278.

Taylor, P. D., L. Fahrig, K. Henein, G. Merriam. 1993. Connectivity is a vital element of landscape structure. Oikos, 68: 571-572.

Taylor, C.A. and M.G. Raphael. 1998. Identification of mammal tracks from sooted track stations in the Pacific Northwest. California Fish and Game. 74(1): p. 4-15.

Terborgh, J., et al., 1999. The role of top carnivores in regulating terrestrial ecosystems, in Continental conservation: Scientific foundations of regional reserve networks, M.E. Soule and J. Terborgh, Editors. Island Press: Washington DC.

Terborgh, J., et al., 2001. Ecological meltdown in predator-free forest fragments. Science, 294: p. 1923-1926.

Theobald, D.M., J.R. Miller, N.T. Hobbs. 1997. Estimating the cumulative effects of development on wildlife habitat. Landscape and Urban Planning 39(1): 25-36.

Tischendorf, L. and L. Fahrig. 2000. On the usage and measurement of landscape connectivity. Oikos, 90(1): 7-19.

Trombulak, S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology, 14, 18–30.

Van Langevelde, F. and C.F. Jaarsma. 2004. Using traffic flow theory to model traffic mortality in mammals. Landscape Ecology, 19: 895-907.

Wheeler, A.P. P.L. Angermeier, and A.E. Rosenberger. 2005. Impacts of New Highways and Subsequent Landscape Urbanization on Stream Habitat and Biota. Reviews in Fisheries Science, 13:141–164, 2005

Whittington, J., C.C. St. Clair, and G. Mercer. 2004. Path tortuosity and the permeability of roads and trails to wolf movement. Ecology and Society, 9(1): 4.

Worton, B.J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. Ecology, 70(164-168)

Zielinski, W.J. and R.L. Truex, 1995. Distinguishing tracks of marten and fisher at track-plate stations. Journal of Wildlife Management, 59(3): p. 571-579.