Wildlife-Crossing Mitigation Effectiveness with Traffic Noise and Light

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A Research Report from the National Center for Sustainable Transportation

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Bobcat contemplating a culvert under Interstate-80
Photo credit: Road Ecology Center, UC Davis

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EXECUTIVE SUMMARY

Wildlife crossing structures (WCS) over or under highways have been proposed as a solution for road-related habitat fragmentation and wildlife collisions. To assure the efficacy of WCS, road-related negative impacts that could cause animals to avoid WCS, such as noise and light, need to be considered. Human-sourced noise can affect habitat occupancy, and a suite of animal behaviors such as vigilance, communication, and predation efficiency, while artificial light, especially at night, can change animal's perception of resources, foraging, mate selection, and navigation. Furthermore, the impact of noise and light varies among wildlife species, leading to differential responses within wildlife communities. To test whether traffic noise impacts species' use of WCS, we quantified overnight (afternoon to early morning) road traffic noise, measured as dB(A), at 20 WCS positioned along four central California highways (I-5, I-80, 680 and 280), as well as historical WCS mammal use for 20 recorded days during the summer of 2012, 2015, and 2016. Using species richness inclusive of all taxa as the response variable, the only significant explanatory variable was annual average daily traffic (AADT) ($p < 0.001$). However, when using disturbance-sensitive species richness as the response variable, we found that sensitive species richness was negatively correlated with maximum noise ($p < 0.05$) and AADT ($p < 0.01$).

Noise levels (dB(A)) and species richness at 8 WCS and adjacent habitats (> 800m from the highway) were monitored over a 20-day period, to further examine the impact of noise on WCS use. Species richness was greater ($p<0.05$) in adjacent habitats (mean 10.6) with low traffic noise levels than recorded at the WCS (mean 7.2). We also examined differences between disturbance-tolerant (e.g., raccoon, striped skunk) and sensitive (e.g., black bear, mountain lion, bobcat, coyote) species. Presence of tolerant species was greater at high noise locations, particularly at underpasses, while the number of sensitive species was lower in noisier areas. We also measured light intensity as total luminescence at eight WCS in the Sierra Nevada and San Francisco Bay Area. We used a novel approach employing a camera with a very wide-angle lens to capture low light levels, combined with software that estimates total illumination and light frequency. There was a suggestive, but not significant inverse relationship between total illumination and species richness, for these eight sites. Our results indicate that wildlife use of WCS could be disrupted by traffic, especially for disturbance-sensitive species. This has important ramifications for using WCS as primary approach to resolve road/highway disruption of wildlife movement and occupancy.

Introduction

Habitat fragmentation and loss due to transportation infrastructure, urban development and agriculture are some of the greatest threats to biodiversity (Wilcove et al. 1998). The ability of a species to disperse among habitats of varying quality is central to population persistence within metapopulations (Hanski 1998). Pimm et al. (1988) demonstrated that isolation resulting from habitat fragmentation can lead to small populations that face increased risk of extinction through inbreeding depression and stochastic events. Landscape connectivity, defined as the degree to which the landscape facilitates or impedes movement among resource patches (Taylor et al. 1993), has emerged as a key component of biological conservation. Mitigation for fragmentation effects of roads includes constructing crossing structures over or under highways to facilitate wildlife passage. However, structure use can vary with taxonomic group and the characteristics of the structure (reviewed in Kintsch and Cramer, 2011). Wildlife movement and behavior have emerged as critical components of connectivity modeling and mitigation in complex landscapes.

Traffic and roads are ubiquitous features of the modern landscape and attempts to mitigate the impacts of these features are central to developing a sustainable transportation system. In addition to habitat loss and fragmentation, roads impact wildlife populations directly through traffic mortality (Jaeger et al. 2005). An estimated 1.5 million collisions with deer occur every year in the U.S. (Gonser, Jensen, and Wolf 2009). These encounters with automobiles are often fatal or injurious for both people and animals, and cost billions of dollars annually. Collisions and habitat loss can push already vulnerable populations, such as highly vagile predators (e.g., mountain lions), into further peril (Waller and Servheen 2005). Counter-intuitively, the greatest mortality may occur on low-traffic roadways, not high traffic-flow highways (van Langevelde et al. 2009), possibly because wildlife have less aversion to minor roads with lower traffic than high-traffic highways. This means that solving wildlife population and community fragmentation by highways will depend on crossing structures being effectively used by many species of ground-dwelling animals.

Fahrig and Rytwinski (2009) found that, overwhelmingly, roads and traffic had a negative effect on animal abundance, but that some species whose main predators show negative population-level responses to roads, experience positive effects on abundance (Fahrig and Rytwinski 2009). Large predators often avoid roads and their associated traffic. Black bears (*Ursus americanus*) in North Carolina shift their home ranges away from areas with high road densities (Brody and Pelton 1989). Mountain lion (*Felis concolor*) home ranges are situated in areas with lower densities of improved dirt roads and hard-surface roads (Van Dyke et al. 1986), suggesting that mountain lions avoid roaded areas. During winter, both elk (*Cervus canadensis*) and mule deer (*Odocoileus hemionus*) in Colorado prefer areas more than 200 m from highways (Rost and Bailey 1979). However, Berger (2007) found that as predator (brown bear) density increased, maternal-moose distances to roads decreased. Since brown bears (*Ursus arctos*) avoid areas within approximately 500 m of roads (Mattson 1990), moose have apparently used roadside corridors as buffers against predation on calves (Berger 2007). Small mammals and lizards will also avoid roads, with the avoidance being almost complete with highways, vs. less developed roads (Brehme et al. 2013). Solving the problem of wildlife aversion to heavily-used roadways is critical to reducing population-fragmentation impacts of busy roads and highways.

Crossing structures are often proposed to mitigate fragmentation effects due to roads. Placements of purpose-built crossing structures are often identified using landscape connectivity models, hotspots of wildlife-vehicle collisions, and/or movement data from radio-collared individuals of focal species. However, other structures may provide unintended conduits for wildlife movement, such as existing drainage culverts, river under-crossings, and railroad underpasses. For the purposes of this proposal we will term these 'opportunistically used wildlife crossing structures'.

Without wildlife use of crossing structures, populations will remain disconnected, may diverge genetically and become lost to stochastic events. This could eventually threaten even common species with local extinction. As climate change is expected to amplify the effects of habitat fragmentation and the impacts of roads (Sala et al. 2000; Travis 2003; Bellard et al. 2012), these crossing structures – intentional or otherwise – will be vital in allowing species to follow their climate envelope as conditions continue to change. However, the species that use intentional and unintentional crossing structures may vary by characteristics of the structure (Clevenger and Waltho 2005; Kintsch and Cramer 2011), with over-passes built for wildlife use having comparable wildlife use to opportunistically used wildlife crossing structures, as long as human use was low (Mata et al. 2008). Variation in wildlife use of structures is likely to include causes such as stochastic light (at night) and noise disturbance from traffic, which have both been shown to affect animal behavior and occupancy (see below). For example, elk use wildlife underpass structures where traffic is absent and at higher-continuous (>14,400 AADT) traffic volumes, but less frequently at intermediate-occasional (0-1,500 AADT) traffic volumes (Gagnon et al. 2007), when traffic noise and light is stochastic. In addition, elk were found to flee mitigation underpasses 37% of the time if a semi-truck went by and 17% of the time in the presence of a passing automobile.

Traffic Noise Effects

Traffic noise can affect a wide range of birds, herpetofauna, and mammals. Traffic noise is measured as sound pressure levels using a logarithmic decibel scale. The range of sound frequencies that wildlife is sensitive to is similar to the range of human audibility (FHWA, 2004), which is usually measured as dB(A), a weighting scheme based on human audibility, or Leq, the equivalent continuous sound level. Human-sourced noise can affect wildlife communication (Parris and Schneider 2009; Owens 2013), habitat occupancy (Goodwin and Chriver 2010), vigilance (Shannon et al. 2014; Li et al. 2009), predation efficiency (Siemers and Schaub 2011), predator avoidance behavior (Meillere et al. 2015) and various other types of behavior (review: Francis and Barber 2013). These effects vary among wildlife species, leading to differential responses within wildlife communities (Francis and Barber 2013), which could affect trophic and other interactions. Recently, McClure et al. (2015) and Ware et al. (2015) experimentally introduced traffic noise into roadless areas to generate what is known as a "phantom road", and demonstrated behavioral and other effects on migrating birds. This was the first direct evidence of traffic noise by itself being the cause of disturbance for birds. Traffic noise is thus both a measurable effect of transportation infrastructure and one that can be mitigated.

Traffic Light Effects

Artificial light, especially at night, can change animal's perception of resources, foraging, mate selection, and navigation (review: Davies et al. 2013) and have cascading ecological and biodiversity impacts (Longcore and Rich 2004; Newport et al. 2014). In a study of the light-detecting pigments of 213 species of arachnids, insects, birds, reptiles and mammals, Davies et al. (2013) found that the effects of artificial light vary with taxonomic group. This difference could affect the interactions among these groups under varying artificial light conditions. Herpetofauna in the field have been found to differentially use crossing structures, which is based in part on light conditions at and within the structure (Woltz et al. 2008). Traffic-sourced light is not continuous in habitat adjacent to roadways and is likely to vary across many orders of magnitude between absolute darkness to very bright within seconds, for low to intermediate traffic volumes. At high traffic volumes and for lighted roadways, artificial light may be a continuous disturbance. Similar to traffic noise, vehicle and roadway light is thus both a measurable effect of transportation infrastructure and one that can be mitigated.

Project Objective

The primary objective was to test whether traffic noise and light impact species' use of WCS, resulting in differential use by species that range in their sensitivity to disturbance.

Approach

Study Areas

Study highways included: I-5, I-80, I-280, I-680, and State Route 65. Structures ranged in size from a 1 m diameter culvert to a 183 m, multi-span bridge over a floodplain. Only two of the 20 were designed for wildlife crossing, the remaining were designed for waterways, railways and roadways, or both. Adjacent habitat ranged from coastal live oak and oak savannah in coastal areas, to agricultural and riparian forest mix in the Sacramento Valley, to montane conifer forest in the Sierra Nevada.

Historical species richness

We first assessed historical species richness and noise condition at all twenty sites which had camera traps positioned at underpasses between 2012 to 2017.

Experimental set up

Historical mammal species observations for 2012, 2015 or 2016 (depending on year of operation) were collected for a 20-day period between the months of April and August. TENMA data-logging sound pressure level meters (PCE Instruments) were deployed during the summer of 2017 to measure noise (dBA) at 1-second intervals between 8pm – 12am (to correspond with crepuscular animal activity, and night-time hours) for one day at each of the 20 sites. From these recordings, the maximum, median and logarithmic average noise (dBA) were calculated for each site.

Species richness in relation to background sites

Secondly, we compared species richness at WCS with richness at quiet 'background' sites during April to August 2017 at a subset of eight of the 20 bridges and culverts that were known to pass at least one species (Figure 1).

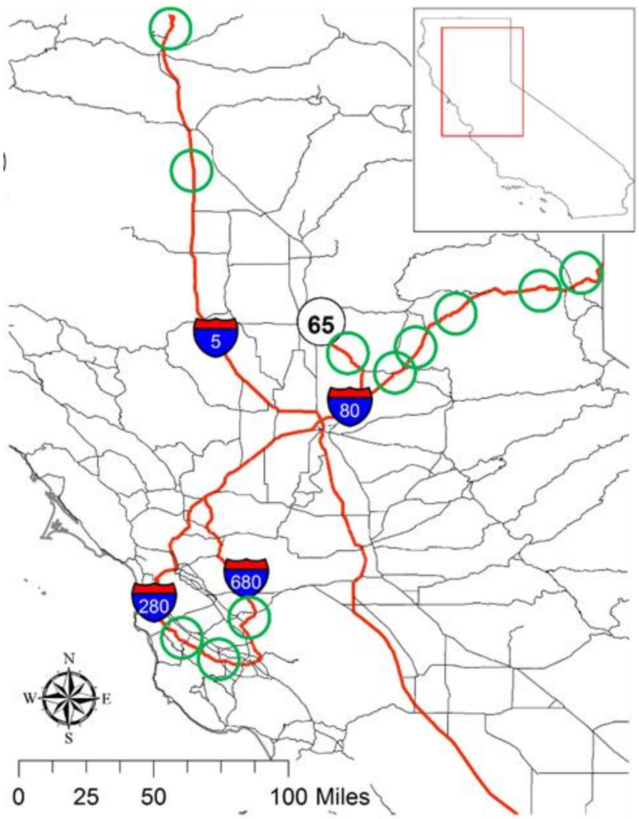

Figure 1. Study area and highway segments

Experimental set up

We used the same model of camera traps across all sites (Bushnell Aggressor Trophy Camera). We used the camera mode, with identical settings among cameras, to monitor species presence. Camera traps were positioned 0.5 m to 1.0 m above the ground facing into or at an angle across the opening of structures (Figure 2). Cameras were positioned adjacent to areas with visible animal tracks. It is possible that more than one camera captured images of a passing individual animal. However, we were only recording whether or not species were present and entering a structure, not counting number of individuals, so camera duplication would not artificially increase species presence counts.

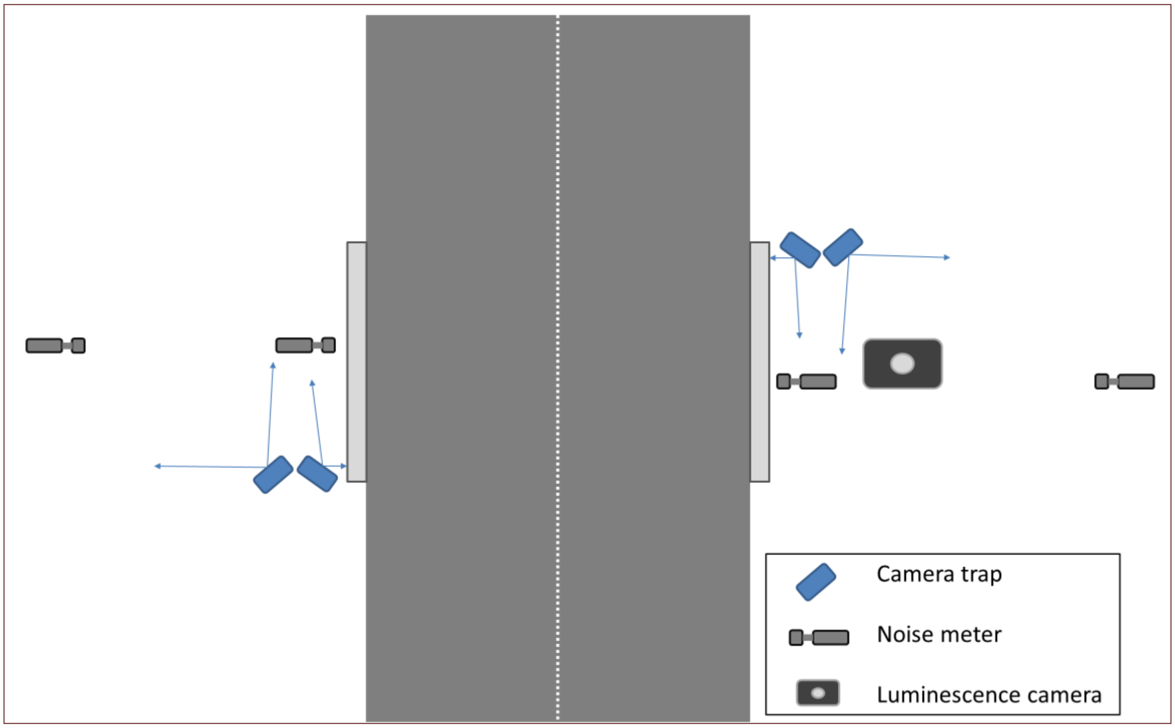

Figure 2. General sampling design at crossing structures

In order to measure background species diversity and further examine the impact of noise on WCS use, we measured the distance to background noise levels from the nearest study WCS (~800 m) and established 4 bait stations with associated cameras, at >100 m intervals, for each pf the eight sites. We used salt blocks, peanut butter, dried corn, grain, and canned cat food in an attempt to attract a wide range of species. We also included four non-baited cameras in these quieter areas, >200 m apart from the baited cameras. Species richness was recorded for 20 days in the summer of 2017, with an overall sampling effort of 96 camera days per site.

We measured traffic noise levels (dBA) at the WCS and the background sites as per the methods for historical species richness. We measured illumination at the WCS using a custom approach from a lab at the University of Southern California that uses a specialized sensor in a digital camera to measure the total illumination in an area, per time unit.

Web-Based Informatics

Data management was supported by a web-based informatics system (the Cam-WON system at the Road Ecology Center, http://wildlifeobserver.net), which includes a large file system for storing images, a database for tracking metadata and integrated data components, and a Content Management System (CMS) to provide a method for human interaction with the data and the project level information, including the locations and placement of the cameras.

Data Analysis

Historical species richness

To explore the effect of noise on historical species richness (2012, 2015 and 2016), we used a generalised linear mixed model (GLMM) with Poisson error. Maximum noise (dBA), underpass openness ratio ((height * width) / length), and annual average daily traffic (AADT) specific to the month that each site was monitored (obtained from the California Department of Transportation (Caltrans) Performance Measurement System) were used as additive explanatory variables and site, year of species observations, and month of species observations as random effects (n = 20). Species richness was further classified according to disturbance-tolerant and sensitive species (Table 1), and a GLMM was performed using the sensitive species richness as the response variable. Species sensitivity to disturbance was determined primarily by reference to the literature (Croonquist and Brooks, 1991; Longcore, 2006).

Table 1. Species that were defined as tolerant or sensitive to disturbance/urban environments.

Species disturbance threshold	Species
Tolerant	California ground squirrel (*Otospermophilus beecheyi*), large rodent, small rodent, mule deer, racoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), Western spotted skunk (*Spilogale gracilis*), Virginia opossum (*Didelphis virginiana*)
Sensitive	black bear, bobcat, brush rabbit (*Sylvilagus bachmani*), chipmunk, coyote (*Canis latrans*), desert cottontail rabbit (*Sylvilagus audubonii*), Douglas squirrel (*Tamiasciurus douglasii*), grey fox (*Urocyon cinereoargenteus*), red fox (*Vulpes Vulpes*), long tailed weasel (*Mustela frenata*), mountain beaver (*Aplodontia rufa*), mountain lion, northern flying squirrel (*Glaucomys sabrinus*), yellow bellied marmot (*Marmota flaviventris*)

Species richness in relation to background sites

Maximum noise and species richness for summer 2017 at underpasses were compared to background habitats using a paired t-test. We then used a linear model to examine the impact of noise and illuminance on 2017 species richness species (n = 8). Stochastic train-related noise was identified as noise peaks >95 dBA for two railroad WCS sites (West Paoli site: peak 103.4 dba recorded at 21:19:12; peak 116.2 dba recorded at 22:49:20; Casa Loma site: peak 95.9 dba recorded at 20:31:51). To examine the potential effect of stochastic train-related noise, we ran all models for the complete noise dataset, and for the noise data that had train-related noise removed (noise measurements were removed 5 minutes before and after maximum dba). All statistical analyses were performed in RStudio version 1.1.383 (RStudio Team 2016).

Results

We made 4 important discoveries related to traffic-related disturbance of wildlife use of crossing structures:

1) Sensitive species are less common at underpasses with greater maximum noise levels and higher traffic volume.
2) Species diversity is lower at the opening of crossing structures compared to nearby habitat areas. This lower diversity generally correlates with the traffic noise at the structure.
3) Artificial light does not play a direct role in influencing species richness.
4) The removal of stochastic train-derived noise made no impact on findings.

Historical species richness

Traffic volume (AADT) was the only predictor of species richness at WCS ($P < 0.001$), however, grouping species by sensitivity yielded a significant decline in species richness at noisier WCS's (n = 20; $P < 0.05$; table 2; figure 3) as well as greater AADT (n = 20; $P < 0.005$; table 2; figure 3). Significant results held true after removing the non-significant terms to prevent overfitting.

Table 2. Results of the GLMM testing the effect of environmental variables on sensitive species richness. Statistically significant results are in bold.

Variable	Estimate	*SE*	*z*	$P(>\|z\|)$
Maximum noise	-3.680e-02	1.777e-02	-2.071	**0.03838**
Openness ratio	-1.410e-02	1.423e-02	-0.991	0.32186
AADT	-1.806e-05	5.922e-06	-3.049	**0.00229**

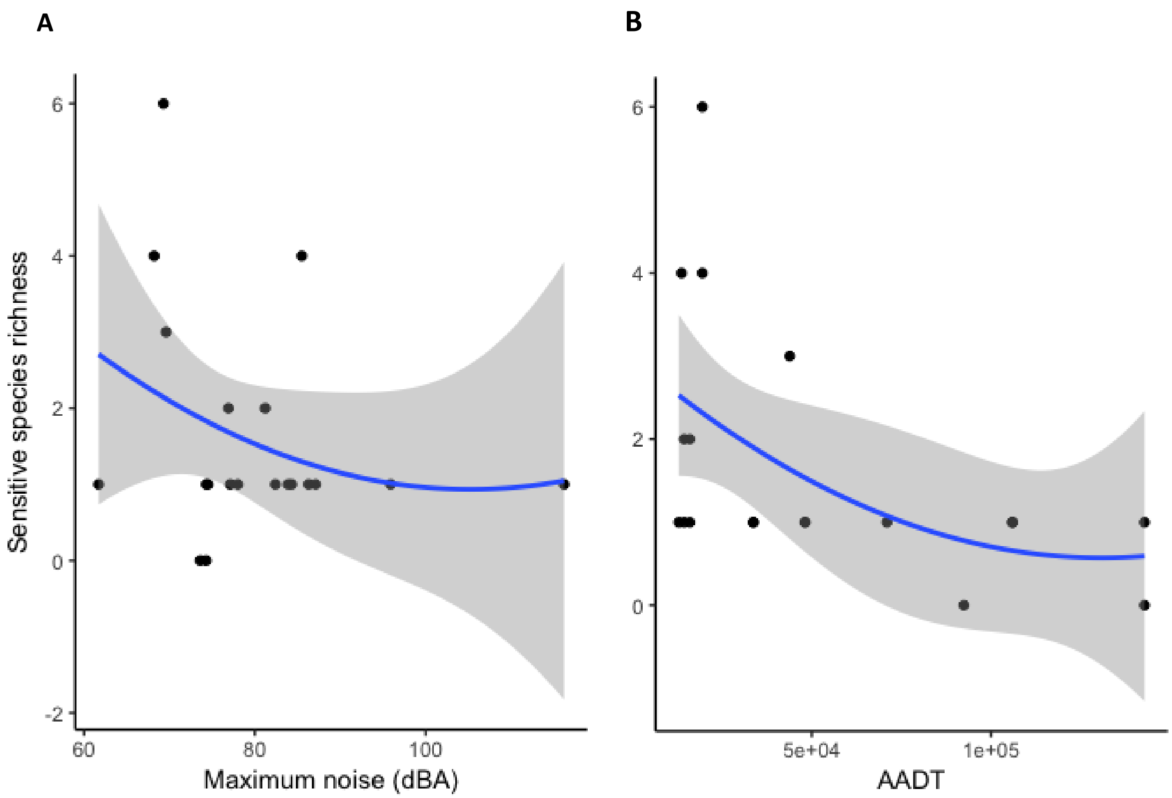

Figure 3. Sensitive species richness for data collected prior to 2017 negatively correlated with A. maximum noise recorded at the wildlife crossing structure and B. highway AADT. Black dots represent the sensitive species richness at each site (n=20), Grey bars represent 95% confidence intervals. Blue line represents a line of best fit.

Species richness in relation to background sites

Mean species richness was 10.6 in the surrounding eight background sites compared to 7.2 at the underpass (paired *t*-test: t = 4, d.f = 7, *P* = 0.005; figure 4A). The surrounding habitat was 13.2 dBA quieter than the WCS (background mean = 46.7 (max dBA), WCS mean = 59.9 (max dBA); *t*-test: t = -3.5, d.f = 7, *P* = 0.009). Maximum noise appeared to slightly correlate with species richness (Figure 4B, linear model: R^2 = 0.1, d.f. = 14, *p* = 0.09). However, we found no interactive effect between treatment (underpass vs background) for noise (max & mean noise linear model: R^2 = 0.3, d.f. = 12, *p* = 0.20) and light (linear model: R^2 = 0.3, d.f. = 12, *p* = 0.1).

The data presented in figure 4 included train-derived maximum noise measurements (dBA). Removing train-derived noise produced comparable results (linear model (max noise): R^2 = 0.3, d.f. = 12, *p* = 0.21).

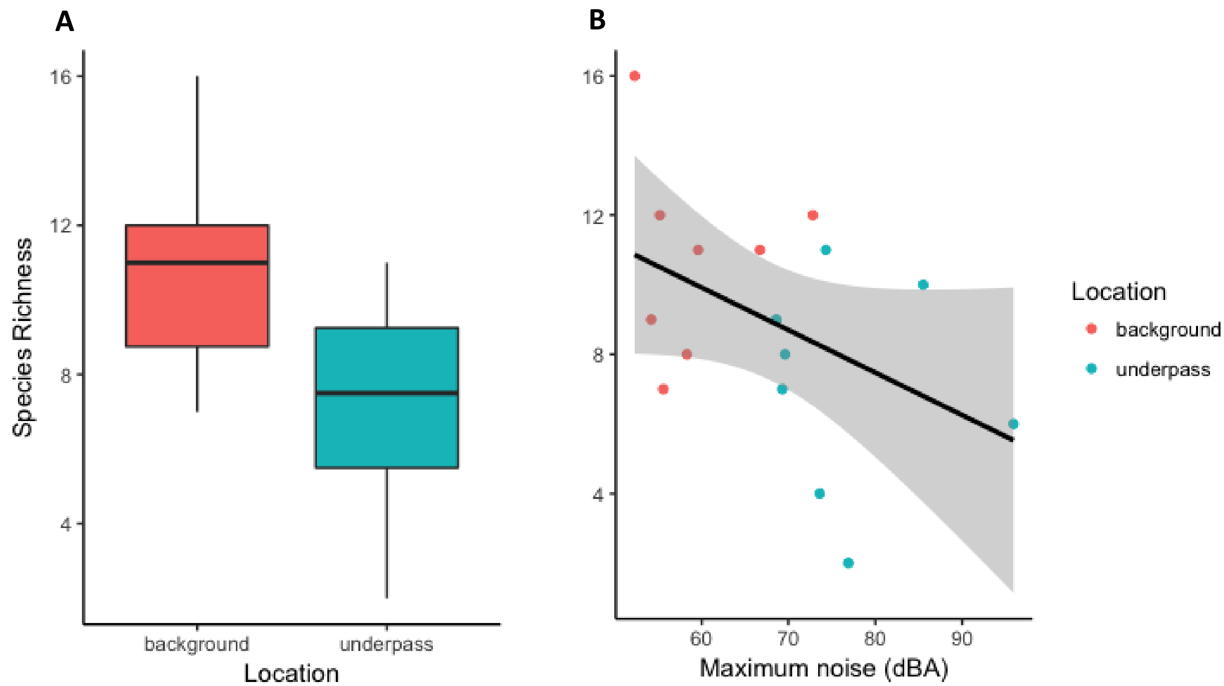

Figure 4. The relationship between species richness and noise represented as A. a boxplot of the species richness for the background habitat and underpass area, and B. the species richness as a function of maximum noise at the underpass and background areas. Black dots represent the sensitive species richness at each site (n=8), Grey bars represent 95% confidence intervals. Black line represents a line of best fit.

Figure 5. Selection of animals observed. From top left: A) Mountain lion near I-680; B) Black bear near I-80; C) Mule deer near I-80; and D) Bobcat crossing under I-80 (photo credits, Road Ecology Center, UC Davis).

Discussion and Conclusions

Wildlife crossing structures (WCS) are seen by transportation organizations and many wildlife agencies as critical to mitigate the barrier effects of roads/highways. They are optimistically assumed to be effective for most species, most of the time, but are seldom critically investigated for this attribute. We found that structures that were built for wildlife crossing and that were opportunistically used by wildlife to cross highways were partially effective at facilitating species movement. We found that there were usually more species in nearby habitat than were using the structures. We determined that the diversity of species using structures was inversely proportional to traffic noise and light conditions at the structure openings. This was especially true for disturbance-sensitive species, suggesting that the species-level findings could be explained by studying the behavioral response of wildlife to traffic noise and light. Because of the cost and conservation expectations associated with WCS, we propose that traffic disturbance conditions be improved for structures where disturbance is excessive and reducing wildlife use. Mitigation retrofit/improvements at structures could include concrete sound/light walls and quiet pavements. Advance noise and light modeling and post-mitigation monitoring should be carried out to inform new WCS design and existing WCS improvements.

Relevant Policies and Agency Activity

DOTs are increasingly responding to wildlife-vehicle collisions and the barrier effects of highways by constructing WCS at locations that are thought to result in reduction of WVC and increased movement of wildlife through the WCS. However, there is little direct guidance for DOTs for how to consider wildlife crossing of highways, except as part of project environmental assessments.

WCS constructed solely to reduce collisions with large animals for the benefit of driver safety are often expected to also provide crossing benefits to other, non-target animals. Other WCS are constructed to provide conservation benefits, especially for threatened or endangered species, or species of concern. In both cases, it is typical for there to be minimal investigation of WCS effectiveness, including finding out why ineffective structures are not attractive for wildlife movement. One assumption is that if WCS are constructed, nearby wildlife will use the structures rather than the road surface. Our research suggests that this can be true, for example across low-traffic highways. However, in the presence of high traffic volumes, wildlife use of WCS may be reduced, especially when the WCS are relatively narrow relative to the length across the right-of-way.

Our research to date suggests several strategies for both estimating potential wildlife use of WCS and for increasing use if the WCS are under-utilized:

1) There are a variety of traffic-related factors that could affect wildlife use of WCS and these should be investigated both prior to building WCS.
2) WCS in areas of extensive habitat and predicted or likely wildlife presence should be screened to reduce traffic noise and light.

Next Steps

We are continuing to examine possible ways to improve our statistical power, using both sampling of additional existing data and collection of new data. Because of the strong effect of traffic volumes on species use of WCS, we also want to understand if there are separate effects of traffic light and noise on wildlife behavior and species richness at the structures.

Specific additional next steps include:

1) Expand the observation period from 20 days to entire seasons to encompass more species visits.
2) Incorporate data for roadkilled wildlife near the WCS to find out whether species not observed at the structures are using the road-surface to cross.
3) Use video recordings to look at the behavioral responses associated with different species choosing to cross through the underpass.
4) Use a richer dataset and understanding of traffic effects to develop noise and light standards for the approach zone (10-100 m from WCS) and the WCS itself to improve WCS use by wildlife in surrounding habitat.

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