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Understanding Behavioral Responses of Wildlife to Traffic to Improve Mitigation Planning

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Understanding Behavioral Responses of Wildlife to Traffic to Improve Mitigation Planning

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A Research Report from the National Center for Sustainable Transportation

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16. Abstract

Creating and maintaining sustainable transportation systems depends in part on understanding and mitigating ecological impacts. Wildlife crossing structures (WCS) are often used to mitigate impacts on wildlife populations. WCS and existing structures may provide passage for multiple species, depending on their sensitivity to traffic disturbance and perception of the roadway. In a previous project, we found that traffic conditions and traffic noise could reduce WCS effectiveness in facilitating passage of diverse and sensitive species. In the current project, we expanded the geographic scope to 26 sites throughout California, including detailed measurements of vehicle noise and lighting impacts on wildlife use of structures. We investigated individual animal behavior as they approached structures as a possible mechanism for reducing species diversity due to traffic disturbance. In order to inform future WCS planning, placement and construction, we studied traffic noise and light impacts on wildlife in the vicinity of the proposed Liberty Canyon wildlife over-crossing (over US 101), the first and largest of its kind in California. We improved a preliminary statistical model of the effects of traffic on WCS use of existing structures. We recommend strategies for transportation agencies to use in developing and modifying WCS to improve wildlife passage.

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Wildlife crossing structures; wildlife-vehicle collision; wildlife connectivity; mitigation; ecologically-sustainable transportation

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Understanding Behavioral Responses of Wildlife to Traffic to Improve Mitigation Planning

A National Center for Sustainable Transportation Research Report

February 2020

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EXECUTIVE SUMMARY

Habitat fragmentation and loss due to transportation infrastructure and land use change are some of the greatest threats to biodiversity (Wilcove et al. 1998). 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. Constructing crossing structures over or under highways can mitigate road-mediated habitat fragmentation, by facilitating safe wildlife passage and reducing the risk of wildlife-vehicle collisions (WVC).

Traffic related light (at night) and noise disturbance have both been shown to affect animal behavior and occupancy (Francis and Barber, 2013; Davies et al., 2013) and have cascading ecological and biodiversity impacts (Longcore and Rich, 2004; Newport et al., 2014). For example, elk use wildlife underpass structures where traffic is absent and at higher-continuous traffic volumes, but less frequently at intermediate-occasional traffic volumes (Gagnon et al., 2007). Traffic-sourced noise and light is likely to vary across many orders of magnitude across different traffic volumes, and attenuate differently at various crossing structures depending on the surrounding habitat.

Wildlife movement and behavior have emerged as critical components of connectivity modeling and mitigation in complex landscapes. The risk disturbance hypothesis predicts that increased noise and light disturbance at certain underpasses could potentially increase an animal's perceived predation risk and time spent being vigilant, thus inhibiting crossings from occurring (Quinn et al. 2006; Shannon et al. 2014). On the other hand, prey may potentially seek out noisier underpasses as a refuge from disturbance-sensitive predator species and exhibit lower levels of vigilance (Berger 2007; Francis et al. 2009).

Our preliminary finding and conclusion from previous work is that increasing traffic volume and resulting traffic noise can reduce sensitive species richness at wildlife crossings. We found suggestive evidence of a similar effect of traffic-sourced illumination. Identifying thresholds for traffic noise and/or light effects would be useful for DOTs and sister agencies engaged in environmental mitigation planning. In addition, understanding the species-specificity of occurrence and behavioral responses to traffic noise and light at or near crossing structures would help with designing future mitigations that are more broadly effective.

The purpose of the project was to measure the significance of traffic noise and light effects on wildlife movement and behavior in relation to highway crossing structures. The three project goals were to: 1) Develop a predictive statistical model for the role that traffic noise and light play in explaining differential use of crossing structures among wildlife species; 2) Study wildlife behavioral responses to noise and light effects at and near the underpass to examine whether the level of species-specific vigilance increases or decreases and; 3) Use the large case study of

the proposed Liberty Canyon wildlife over-crossing and preceding information to recommend standards for mitigating the effects of traffic noise and light on wildlife use of impacted crossing structures.

In the current project, we investigated traffic noise/light conditions and wildlife presence/behavior at 28 sites along 4 interstate, 11 state highways and one major county road spread across California. These sites and highways represent most of the species groups and bioregions of California (e.g., Sierra Nevada range). To measure and model changes in wildlife behavior and presence, we used motion and heat-sensitive camera traps, sound level meters, hemispherical photography to measure illuminance, and location characteristics. We developed statistical models to examine changes in wildlife presence and behavior.

We found that wildlife respond in several important ways to traffic noise and light at wildlife crossing structures (WCS): 1) Presence – certain species were more sensitive to traffic disturbance than others and less-frequently observed; 2) Activity – there was less animal activity near very loud WCS; 3) Behavior – Certain species were more vigilant than others in the presence of noisier WCS; 4) Thresholds – noise levels above 60-70 dBA, hemispherical illuminance above ~100 mlux and traffic levels above 10,000 cars/day were correlated with significantly reduced wildlife-use of WCS. These findings indicate that wildlife species respond to and use WCS differently from each other and that there are thresholds of traffic disturbance that should be used in designing new structures and to retrofit existing structures.

The camera trap data are available at: https://wildlifeobserver.net/projects/noise-and-light-pollution. Noise and light data are available upon request (fmshilling@ucdavis.edu).

Introduction

Traffic can be a source of noise (night and day) and light (night) disturbance for wildlife sensitive to artificial noise and light. 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 and across tens of meters, 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.

Vehicle 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 vehicle 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 vehicle noise by itself being the cause of disturbance for birds. Herpetofauna (amphibians and reptiles) are also vulnerable to vehicle noise, primarily low-frequency vibrations, which can cause harmful behaviors, such as emerging from burrows during dry conditions (Gridi-Papp and Narins, 2010). Wildlife are sensitive to the range of sound frequencies in vehicle noise and which is similar to the range of human sensitivity (FHWA, 2004). The loudness across this range of frequencies is usually measured as dB(A), a weighting scheme based on human audibility, or Leq, the equivalent continuous sound level.

Expected Sound and Light Decay with Distance

Assuming a starting noise level of 96 dBA (legal limit for motorcycle noise) on a roadway, a theoretical sound level of 55 dBA could be expected at ~110 m from the sound source (red arrow, Figure 1) and a sound level of 45 dBA at 355 m from the sound source (orange arrow, Figure 1). The rate of change in noise level is the inverse square of the distance. The observed transmission and decay of noise with distance is usually not the same as the theoretical, as noise can be absorbed and reflected by elements in the environment (ground, vegetation, structures). The actual distance of noise decay to particular sound levels defines the noise component of the road effect zone away from the traffic/roadway. This zone can be mapped using either noise propagation models or field noise measurements, or both.

Light dissipation with distance is superficially similar to sound decay, but in real environments may result in different outcomes. Light intensity decreases with the inverse square of distance, just as sound does. Light intensity is measured as either radiance or irradiance with associated spectral properties and can be quantified using light meters and specialized light-collection systems, such as the one used in this study. Similar to the case with noise, the expected transmission and decay of light with distance is usually not the actual distance as light can be absorbed and reflected by environmental elements (ground, vegetation, structures). The actual distance of light propagation to particular levels defines the light component of the road effect zone away from the traffic/roadway. This zone can be mapped using either light propagation models or field light measurements, or both.

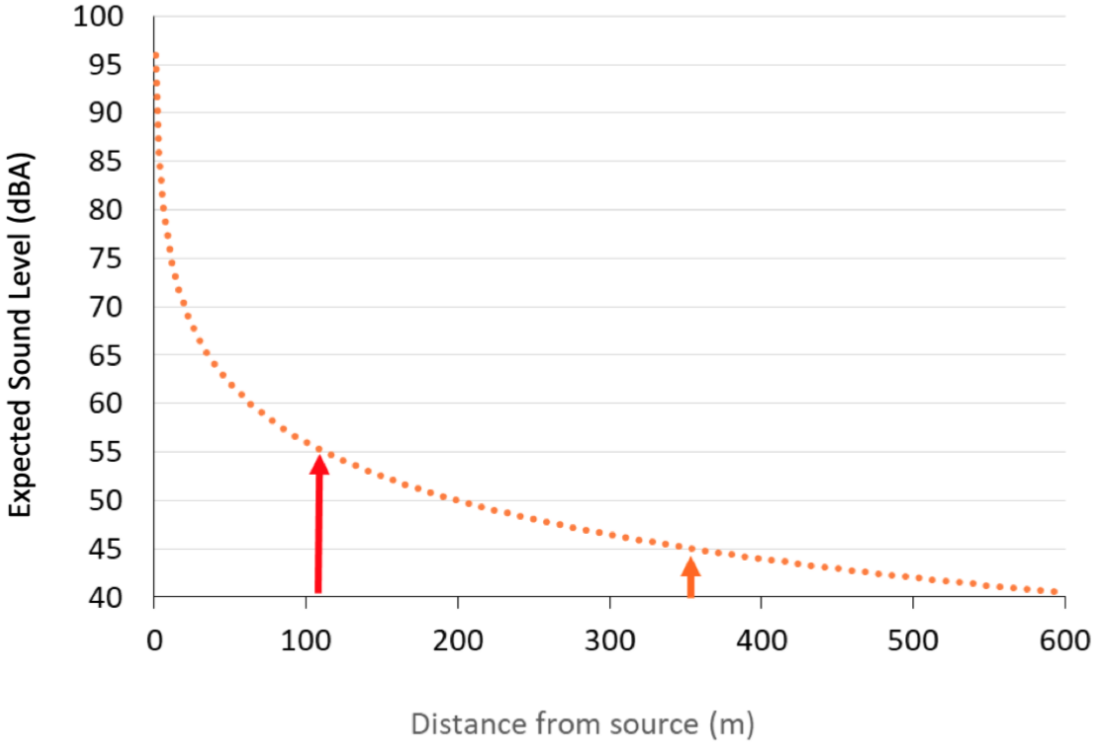


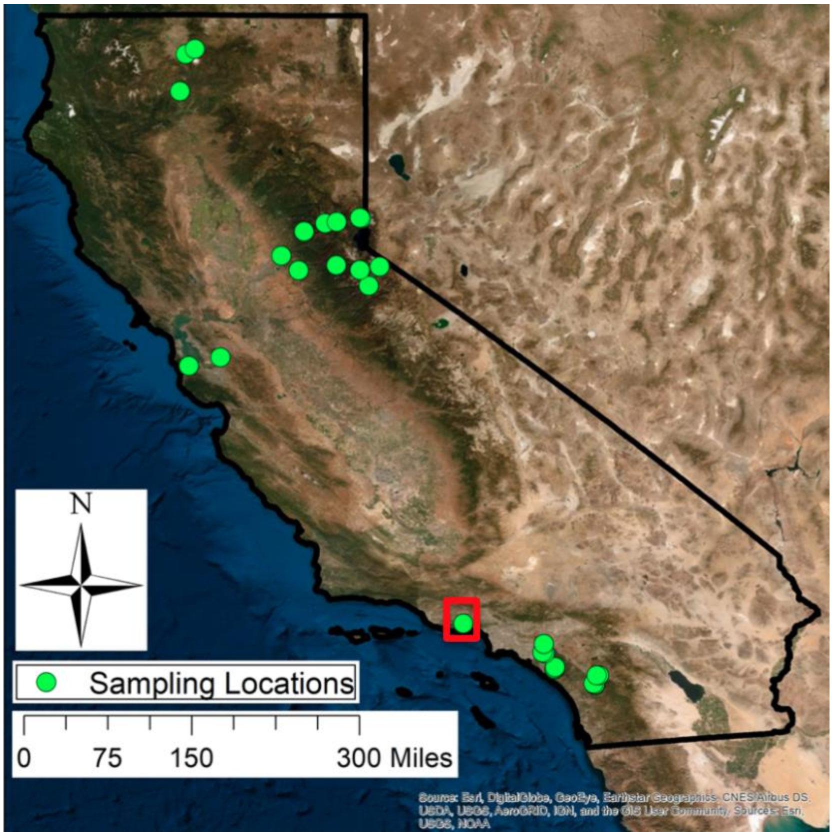
Figure 1. Rate of decay of vehicle noise with distance, starting at a level characteristic for motorcycles (96 dBA). The red arrow indicates the distance (~110 m) where a sound level of 55 dBA would be expected. The orange arrow indicates the distance (~355 m) where a sound level of 45 dBA would be expected.

Measuring Wildlife Presence and Behavior

Wildlife presence, movement, and activity can be monitored using motion/heat-triggered, remote cameras ("camera traps"). Motion-triggered cameras were first used to photograph wildlife in the 1890s (Hance, 2011), but only after the advent of infrared triggers in the 1990s have been used to detect wildlife. Camera traps are a valuable and increasingly-used instrument to detect wildlife presence and in a limited way, study wildlife activity (Rowcliffe et al., 2014). There is also detailed guidance for using cameras and standardized reporting data from cameras for ecological studies (Meek et al., 2014).

Study Area

We extended our previously-used study sites in Northern California to include sixteen locations in North-Central California (I-5, I-80, I-280, I-680, and State Route 4, 50, 76, 88, 89 and 97), twelve locations in Southern California – the Santa Ana mountains in Orange and Riverside counties (Santiago Canyon, SR 74, 76, 79, 91,) and the Santa Monica mountains in Los Angeles county (US 101, Figure 2). Sites in the Santa Ana mountains of southern California have been identified as important barriers to mountain lion movement (W. Vickers, Pers. Comm.), and the Santa Monica site, herein referred to as Liberty Canyon, provides us with a unique opportunity to implement a Before-After-Control-Impact design, in which we can quantify the baseline state of the site's wildlife visitation before a wildlife structure is erected. Sites with existing structures were chosen because they represented common types of structures where wildlife movement could be expected (e.g., box culverts, bridges over waterways, wildlife crossing structures). Two of these sites ("Mesa 2" site, SR 74; "PM24" site, I-80) identified as box culverts were further used to examine wildlife activity.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community, Sources: Esri, USGS, NOAA

Figure 2. Locations of sampling (green dots) for wildlife and traffic disturbance alongside roadways in California and the approximate location of the Liberty Canyon wildlife crossing (red square).

Methods

Traffic Noise and Light Measurements

Sound pressure levels were recorded in A-weighted decibels (dBA) and C-weighted decibels (dBC) using digital sound level meter devices (TENMA 72-947 and PCE-322; 30-130 dBA/C range, set to slow). To correspond to timing of crepuscular and night-time activities, we sampled sound levels for one evening (11pm – 2am) at 1-second intervals within a) the crossing structure entrance and b) the closest camera station in the background area. To characterize overall sound conditions at the structures, after the camera trapping period, we collected dBA and dBC sound pressure levels at the crossing structure entrance for one week at 59-second intervals.

Low-level light intensity as total hemispherical luminescence illuminance was measured along a 50m transect away from each of the 26 crossing structures (0m, 10m, 30m, 50m). We used a novel new approach employing a camera with a very wide-angle lens to capture low light levels that is calibrated and processed with specialized software (Sky Quality Camera, Euromix Ltd., Llubjana, Slovenia; Jechow et al., 2017, Figure 3). All light measurements were taken during a new moon.

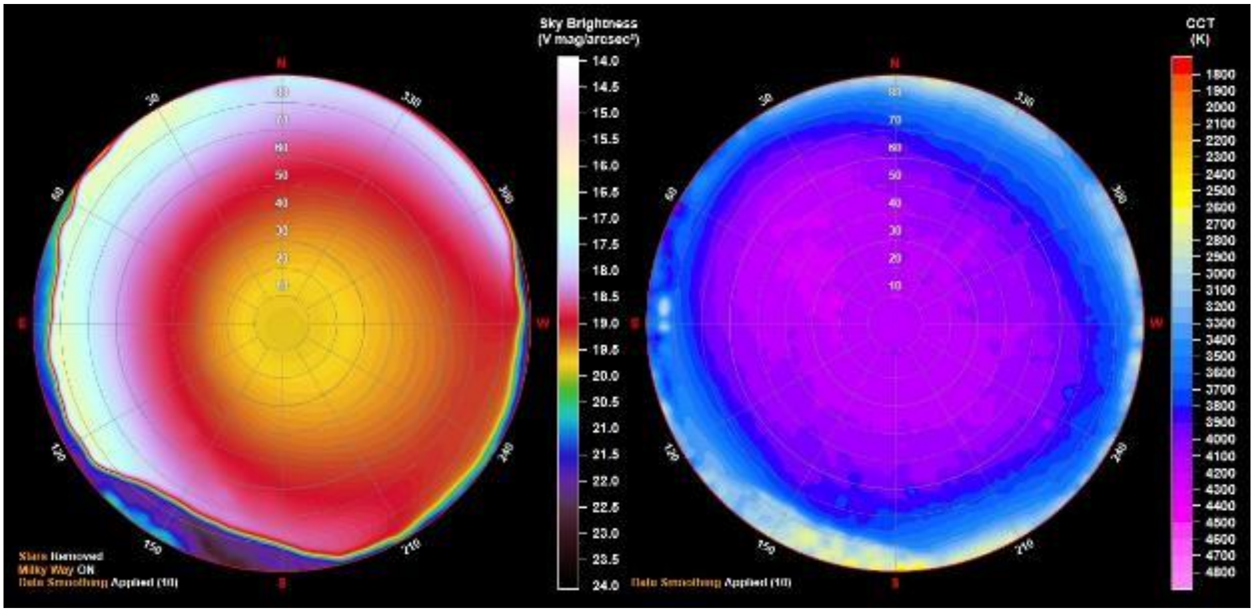


Figure 3. Example of images collected by the specialized light-measuring cameras for scalar illuminance measurement. The image on the left shows brightness and the image on the right correlated color temperature (CCT), where reds and yellows indicate "warmer" colors (e.g., sodium lights) and blues and purples represent "cooler" colors (e.g., LED lights and deep space).

At the Liberty Canyon site, noise and light measurements were taken along three transects (0 – 500m); one canyon and one ridge located north-east of the proposed crossing on highway 101, and one transect south of the highway 101 (Figure 4). Noise measurements were taken for 2 minutes, at 1-second intervals. We also collected a second set of noise measurements for approximately 15 minutes at the 18 locations of video camera stations set in the north-east approach zone (Figure 4; see wildlife activity for camera information). Finally, a third set of 15-minute noise recordings were collected throughout the north-east approach zone, spanning 0 – 1000m (Figure 12).

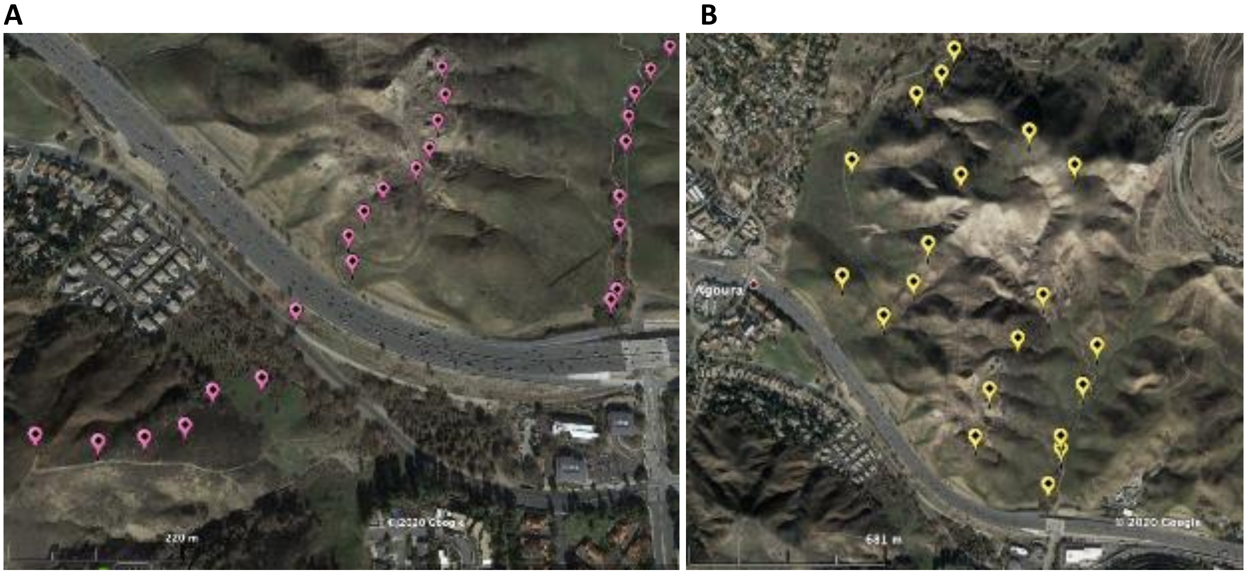


Figure 4. Locations of A) 2-minute noise (dBC and dBA) and light measurements sampled simultaneously (pink markers) and B) Browning camera stations and 15-minute noise (dBC and dBA) measurements (yellow markers).

Habitat Classification in the Surrounding Landscape

We characterized habitat surrounding each structure using 16-class land cover data from the 2016 National Land Cover Dataset (NLCD, US Geological Survey), which has a spatial resolution of 30 m^2. For each underpass, we classified land cover within a 100 m^2 radius and 1 km^2 radius buffer in ArcGIS to determine whether habitat in the approach zone and background area respectively influences species-specific movement on a small and/or large scale and noise attenuation.

Species Detection at Wildlife Cross Structures in Relation to Background/Control Sites

We compared species detections at wildlife crossing structures (WCS) with detections at quiet ‘background’ camera stations for 26 crossing structure sites (Figure 2). These sites can b thought of as a type of “control” for the WCS, though they are not controls in the formal sense of within an experiment. We used the same model of camera traps across all sites (Bushnell Aggressor Trophy Camera). We set each of the cameras to capture still images and have a minimum of three seconds between trigger events, and one trigger event at a time. Four camera traps were positioned at the WCS 0.5 m to 1.0 m above the ground facing into or at an angle across the opening of structures (Figure 5).

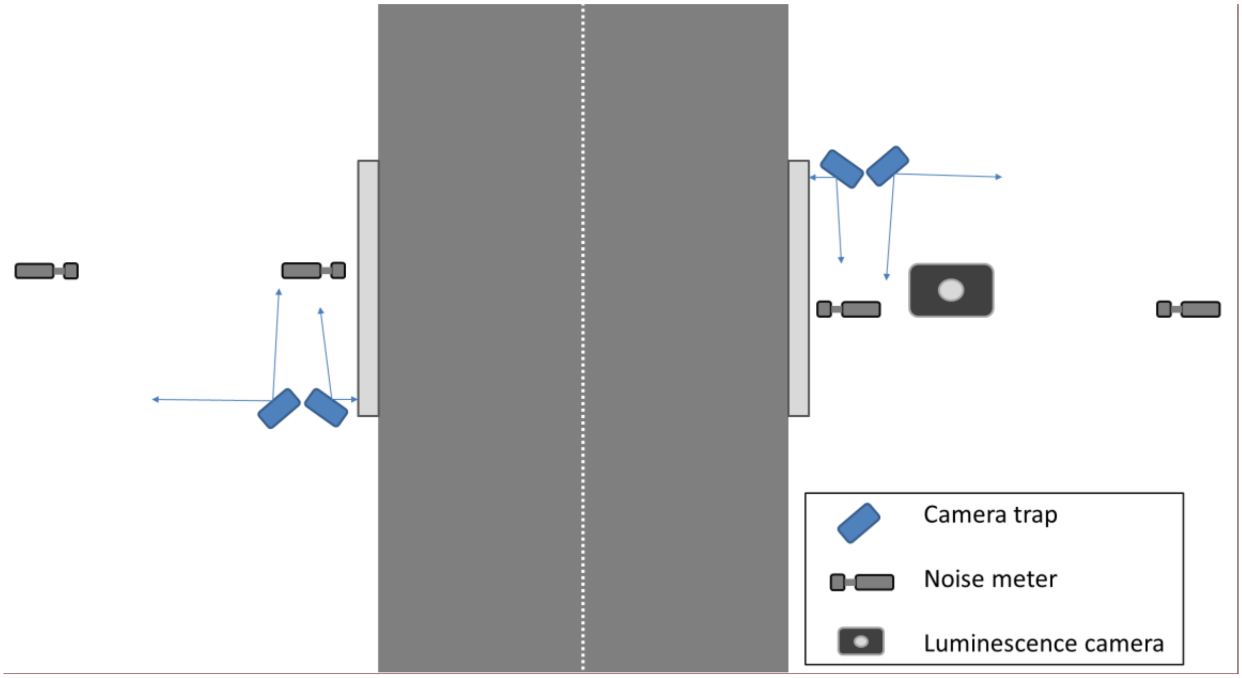


Figure 5. General sampling design at crossing structures.

In order to measure background species detections and further examine the impact of noise on WCS use, we measured at increasing distance from the WCS until sound levels had reached background noise levels (~800 m), defined as levels that did not change appreciably with increasing distance from the WCS. We established four bait stations with associated cameras, at >100 m intervals, for each of the sites (Figure 6). We used salt blocks, peanut butter, dried corn, grain, canned cat food, and chicken parts in an attempt to attract a wide range of species. We also deployed four non-baited cameras, >200 m apart from the baited cameras. Cameras were positioned adjacent to areas with visible animal tracks. Cameras were set to have a 10-second delay between trigger events due to the high occurrence of false triggers caused by vegetation.

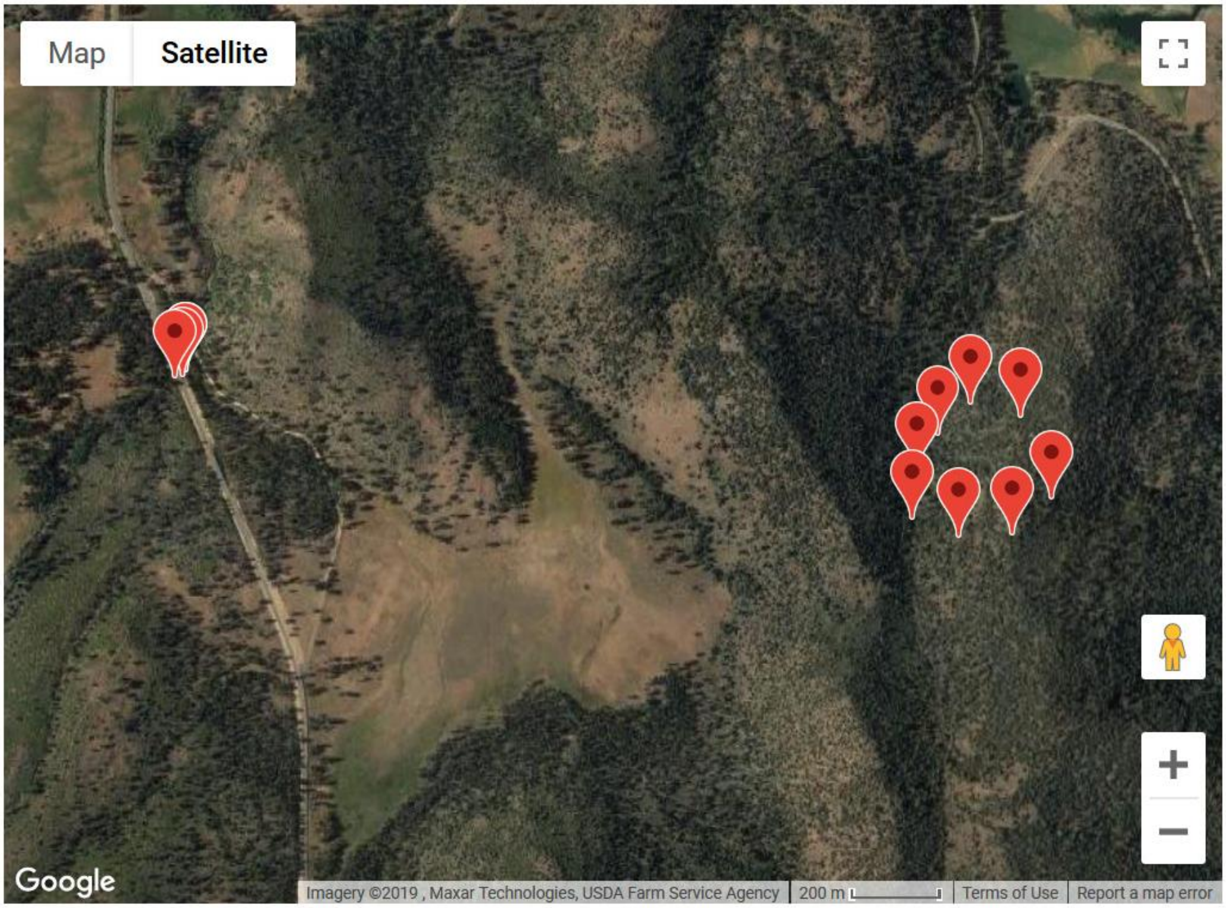


Figure 6. Example highway and background location (Highway 89) showing the relative positions of cameras (red markers) at the highway crossing structure and background.

Web-Based Informatics

Data management was supported by a web-based informatics system (the Cam-WON system at the Road Ecology Center, https://wildlifeobserver.net), which includes a large file system for storing camera trap images (Figure 7), 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.

The camera trap data for this project is available here: https://wildlifeobserver.net/projects/noise-and-light-pollution.

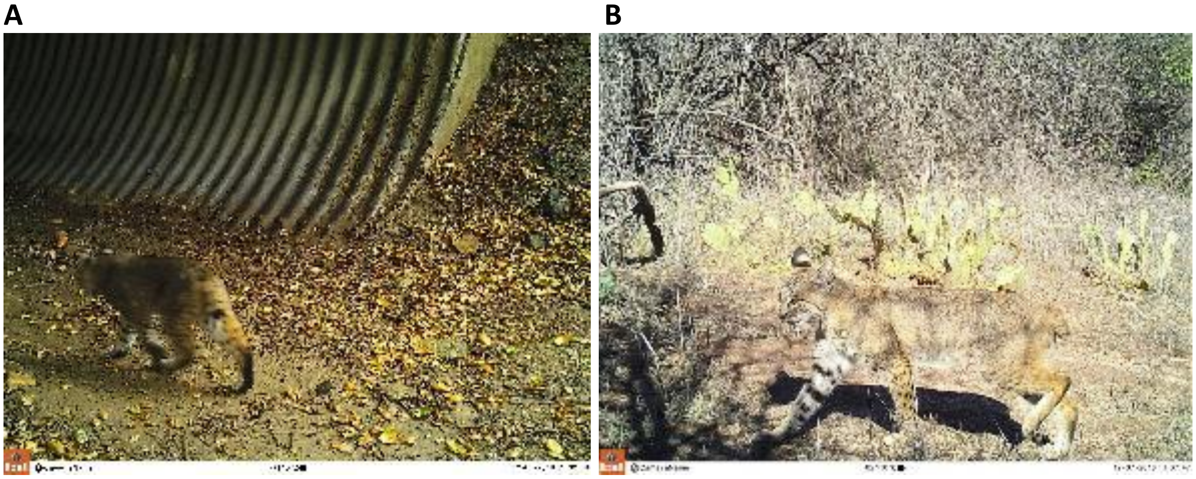


Figure 7. Bobcat at A) a highway crossing structure and in B) a background area.

Wildlife Activity

To assess wildlife activity (hereafter referred to as “behavior”), sets of six Browning Dark Ops Pro cameras were set to video mode and one set deployed at and near each of two highway crossing structures for two months (*n* = 2 sites; “Mesa 2” site, SR 74; “PM24” site, I-80) and 18 sites at the proposed Liberty Canyon wildlife crossing structure for three months (Figure 4). Based on preliminary data collection for deer and coyote, 20 types of behavior were extracted from videos as point events or state events (Table 1). The activities were grouped into two categories of behavior (Table 2). Species identification and behavior time budgets were extracted from all videos using the Behavioural Observation Research Interactive Software (BORIS; Friard and Gamba, 2016; Figure 8). The number of humans and domestic dogs present were recorded for each video. In addition, for videos deployed at the highway crossing structures, we classified traffic within a video recording into one of three categories: 1) continuous traffic, 2) occasional, distinguishable traffic, representing between 1-5 clearly audible vehicles passing at random intervals, and 3) zero traffic.

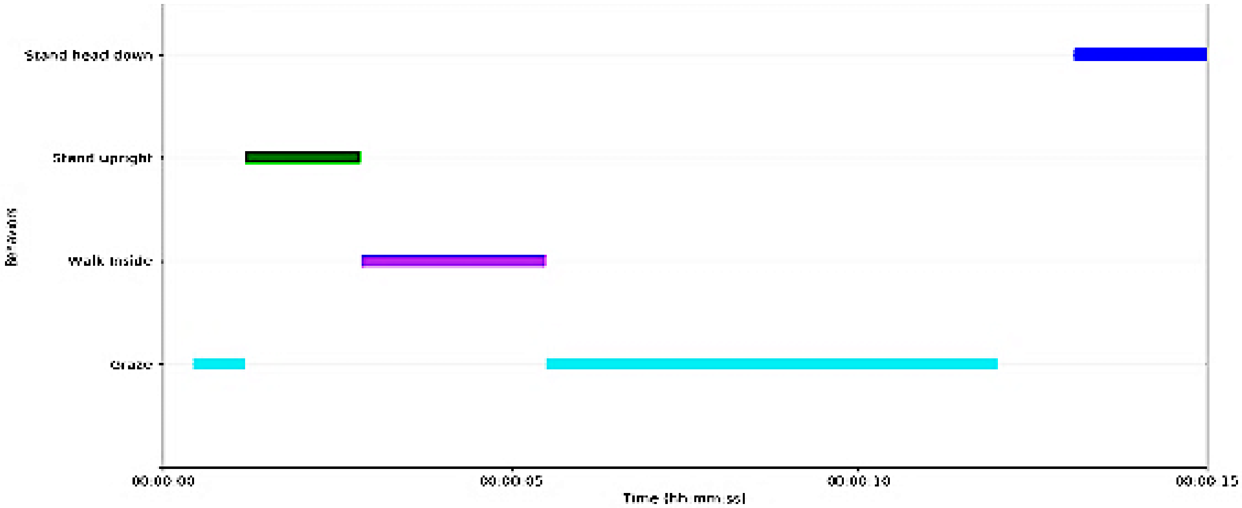


Figure 8. Example of a deer time-budget for one 20-second video.

Table 1. Ethogram describing specific mammalian activity patterns observed at underpasses

Code	Description	Category
Repel	The point at which an animal turns away from the underpass	Locomotion
Enter	The point at which an animal enters the underpass	Locomotion
Walk toward	Walk in the direction of the underpass	Locomotion
Walk out	Walk in the direction away from the underpass	Locomotion
Walk	Walk without a purposeful direction	Locomotion
Trot/jog	Animal trots in any direction	Locomotion
Run	Animal runs in any direction	Locomotion
Carry object	Specify whether this is offspring or a prey item	Locomotion
Jump	Animal jumps	Locomotion
Rest	Animal is laying or sitting down	Locomotion
Graze	Animal has head to the ground, visibly masticating	Foraging
Drink	Animal has head to the ground, visibly taking in liquids	Foraging
Groom	Animal is grooming	Physiological
Defecate	Animal is defecating	Physiological
Urinate	Animal is urinating	Physiological
Allogroom	Groom a conspecific	Social Interaction
Vocalize	Auditory cues to conspecific	Social Interaction
Display aggression	Animal shows signs of aggression toward a conspecific (lurches forward, attempts to bite, snarl)	Social Interaction
Stand head up	Upward movement of head while looking at surroundings	Vigilance
Stand head down	Downward movement of head while looking at surroundings	Vigilance
Ear twitch	Movement of ear(s) indicative of being alert	Vigilance

Table 2. Summary of the ethogram describing specific mammalian activity patterns

Behavior Category	**Specific Activity Recorded**
Non-vigilance	Aggression, exploration, graze, groom, rest, walk, socialize, stand head down, urinate, sniff
Vigilance	Run, trot/jog, Stand upright

Statistical Analyses

1. Species Richness at WCS

To initially assess whether species richness differed from the background site and the underpass, we used a linear model. To examine species richness at the wildlife crossing structures (WCS, fraction of species detected by baited and unbaited cameras in the background areas) as a function of noise and light for the 26 sites, we used a generalized linear model with Poisson distribution. We included elevation, WCS width and length, number of human daily visits, traffic count, NLCD habitat class, fencing (present, absent), CA location (South, central and North), presence of flowing water (present/absent), and sampling season (Summer, winter, autumn) as covariates. We then conducted a stepwise model selection using the R package ‘step’. Finally, we addressed whether any species-specific avoidance of the underpass was occurring. Using the continuous covariates listed above, we performed logistic regression for species that were observed at >20 sites: deer, bobcat and coyote.

2. Traffic Noise and Light at Liberty Canyon

To first identify whether there is a relationship between noise, light, and distance from the highway at the proposed Liberty Canyon crossing structure, we applied a linear model to examine whether a correlation exists between nighttime light, simultaneously measured nighttime noise (2 minute recordings, dBA and dBC), and distance (100 - 500m), measured across three transects (two ridges and one canyon).

3. Noise Impact on Species Richness at Liberty Canyon

To identify whether certain species avoid noisier areas that are closer to residential areas within the approach zone of the proposed Liberty Canyon overcrossing, we performed a linear model to assess species richness at each camera station. To explore whether species tolerance to noise is based on a threshold-response, we conducted a logistic regression of presence probability for four species: bobcat, coyote, deer and striped skunk.

4. Noise Impact on Species Behavior

To address whether levels of vigilance are altered at noisier areas within the approach zone of Liberty Canyon, we performed a linear random-effects model, using proportion of time spent being vigilant as the explanatory variable, 15-minute maximum noise (dBA) recorded at each camera station, distance from the highway, and human presence as the explanatory variables, with transect number as a random effect. Due to the human presence data containing a high number of zeros, we added a constant value of 1, and performed a log transformation. For this analysis, we focused on coyote and deer as the number of observations for bobcat and skunk were too low.

To explore deer vigilance at two wildlife crossing structures: Mesa 2, PM24, in response to three differing classes of vehicle presence, continuous, distinguishable, and zero vehicles, we used a generalized linear model with a binomial function due to the response variable being proportional data.

Results

1. Species Richness at WCS

For the 26 crossing structure sites, we detected fewer species at the underpass than in the background ($p = 0.000002$; R^2 adjusted = 0.4; *SE* = 0.5; Figure 9). The mean number of species present at the underpass was 3.6 (range: 1 – 8; CI: 2.9 – 4.3), compared to a mean of 6.2 (range: 3 – 9; CI: 5.6 – 6.9) for the background.

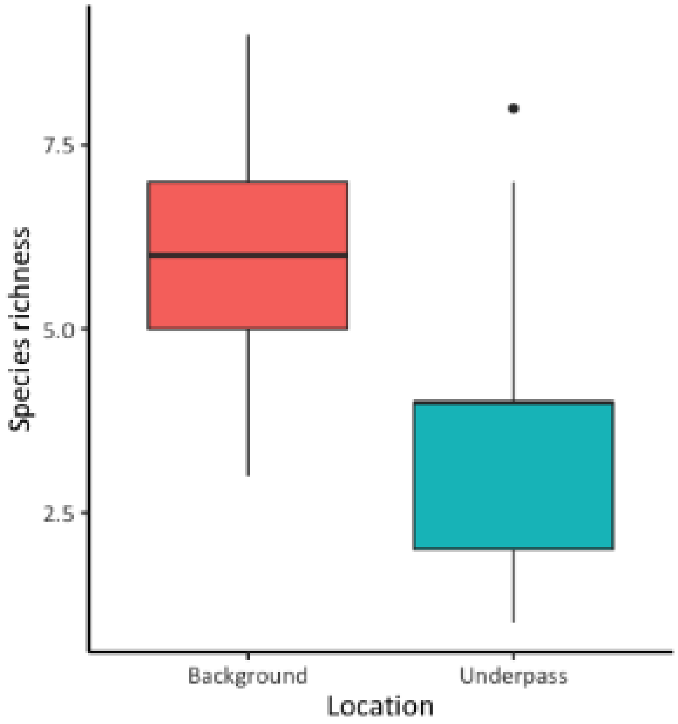


Figure 9. Species richness at background and underpass sites.

The proportion of species in the background areas detected at the underpass was lower in areas of greater noise levels (minimum dBC, 1 week recording length, $p = 0.04$; $n = 26$; Figure 10). Species richness was also lower at southern sites in California ($p = 0.009$; Figure 10) and greater in the winter sampling period compared to the autumn period ($p = 0.03$; Figure 10).

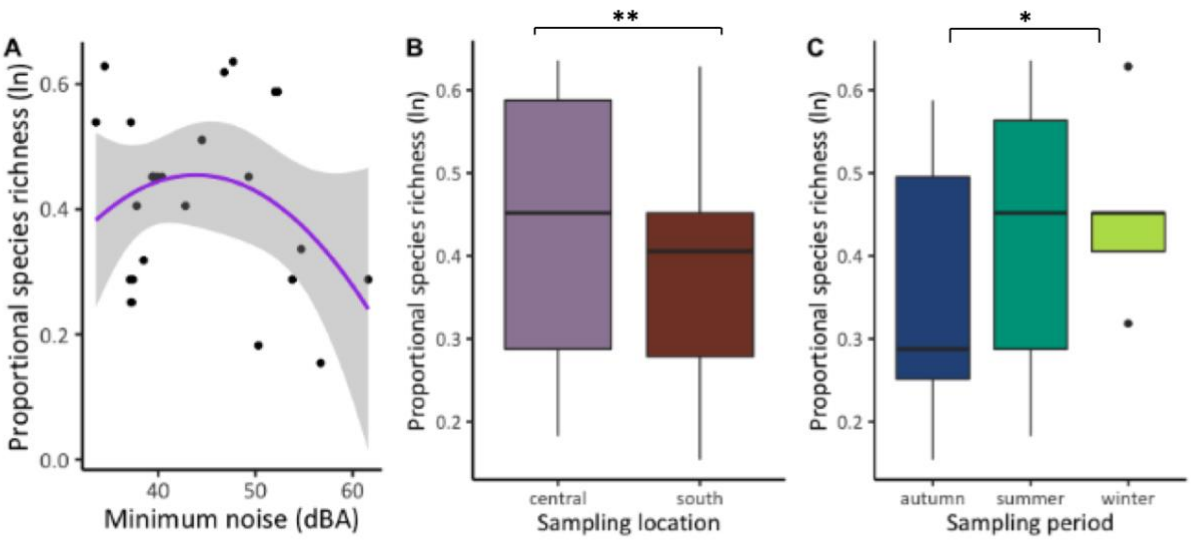


Figure 10. Species richness as a proportion of total species detected in the surrounding region and A) Minimum week-long noise recordings (dBA) B) Sampling location and C) sampling period.

Results from our species-specific analyses demonstrated bobcat and deer display no clear alteration in probability of presence at a wildlife crossing structure (WCS). Coyotes on the other hand were more likely to be present at WCS that were shorter in length (*p* = 0.05; *n* = 21; Figure 11). For individual species, there was no clear predictive response to noise or light disturbance.

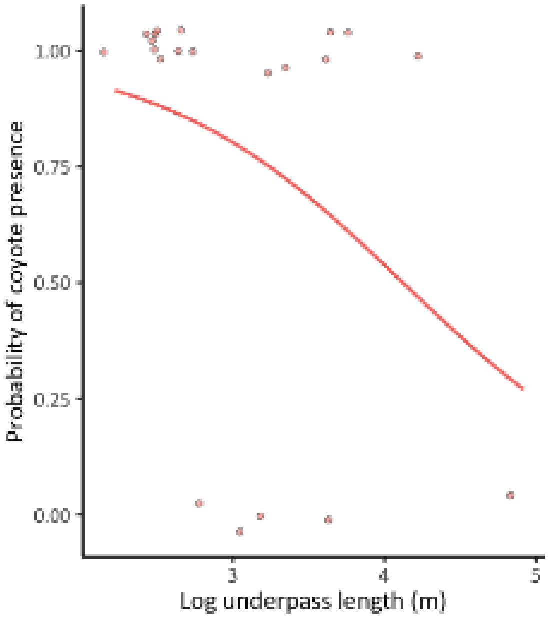


Figure 11. Relationship between underpass length (log) and probability of the coyote being present at the WCS. Red circles represent whether the coyote was present (probability of presence = 1) or absent (probability of presence = 0) from each of the 21 sites for which we detected coyote in the background.

2. Traffic Noise and Light at Liberty Canyon

Based on the three sound and light transects we completed at the Liberty Canyon site, median and maximum dBA (2-minute recording; Figure 12) and dBC (2-minute recording; Figure 12) noise correlated negatively with transect distance (p = 0.0001). However, noise did not correlate consistently with distance from road when examined in a grid of sampling stations in the northern approach zone to the proposed Liberty Canyon crossing, ranging in distance 100 - >1,000 meters across a >1 km area (third set of noise measurements; Figure 13). This demonstrates the complexity of noise propagation and perception across a highly geoorphologically-variable landscape.

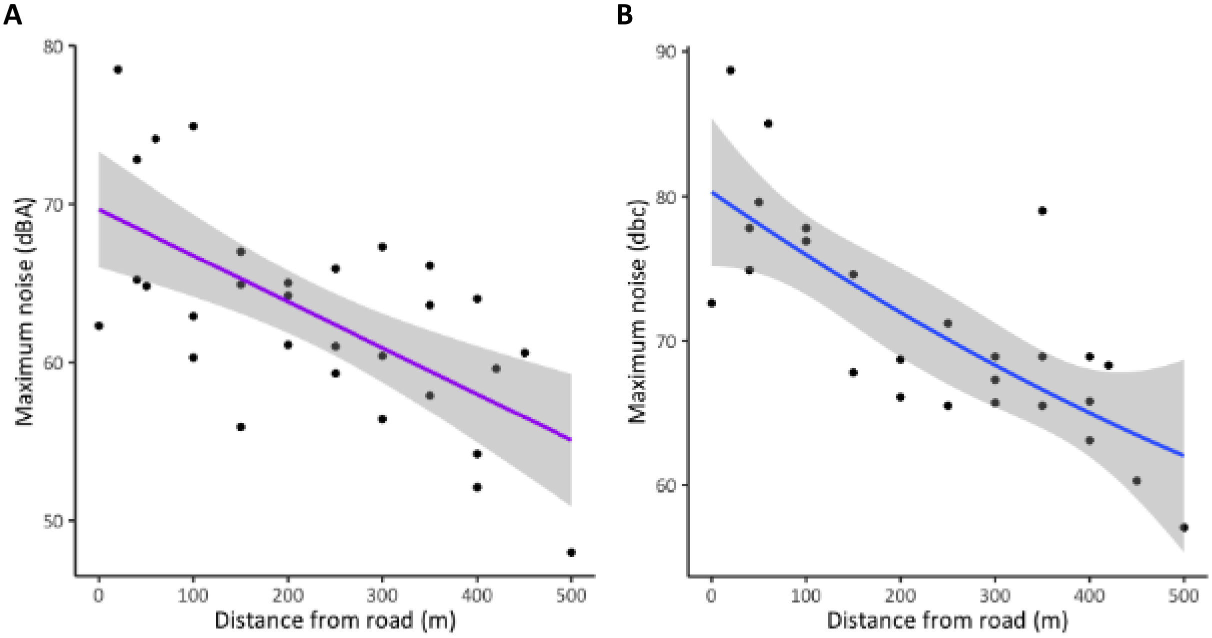


Figure 12. Noise decay with distance from the proposed location of the Liberty Canyon wildlife over-crossing in A) dBA and B) dBC.

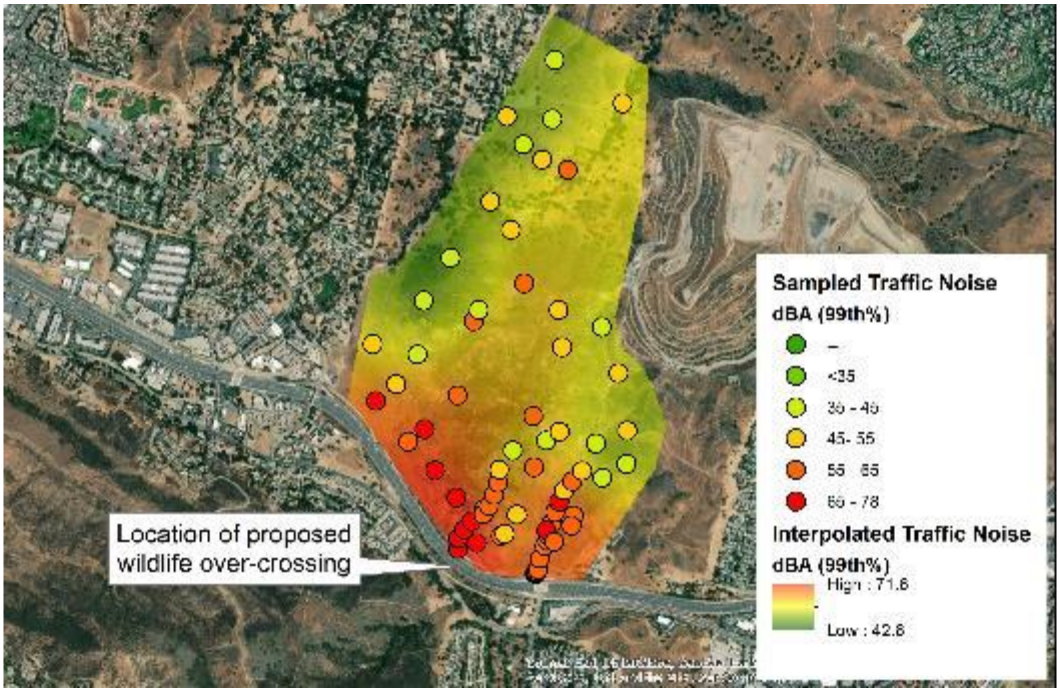


Figure 13. Sampled noise levels (dBA, points) and noise interpolated from sampled noise (dBA, red-green scale) across the area through which wildlife would approach to get to the proposed Liberty Canyon wildlife over-crossing. Interpolation was carried out using Kriging in ArcGIS with 10m resolution and a 100m radius search distance.

Median dBA (2-minute recordings) and median dBC noise was found to be the only noise measure to correlate with light (dBA: *p* = 0.02; *SE* = 0.05; *adjusted R2* = 0.5, Figure 14 and dBC: *p* = 0.017; *SE* = 0.04; *adjusted R2* = 0.6, Figure 14).

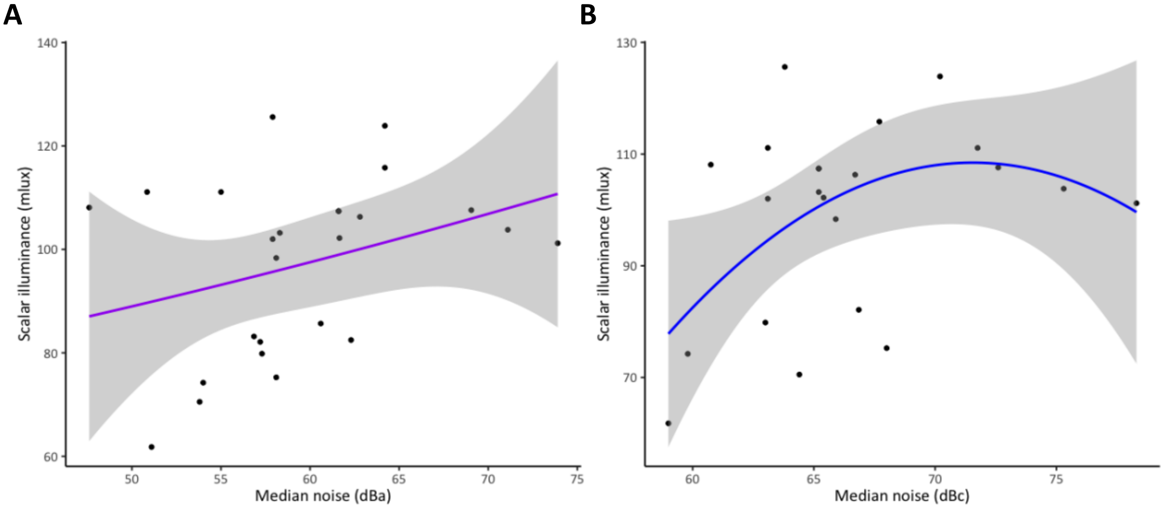


Figure 14. Relationship between scalar illuminance and median noise in A) dBA and B) dBC.

Scalar illuminance did not correlate with distance from road, indicating that unlike noise, factors other than distance from the highway influence the distribution of illumination across the landscape at Liberty Canyon. Unlike noise, light can be blocked by obstructions, so topography and vegetation barriers can eliminate the effects of direct glare. Over half of the sample locations had illumination levels exceeding that produced by a full moon, indicating a highly light-polluted environment.

3. Noise impact on species richness at Liberty Canyon

Maximum noise (dBA) recorded at each camera station (15-minute recordings) was negatively correlated to species observed over a 3-month period (*p* = 0.01; *adjusted* R^2 = 0.4; *SE* = 0.03; *n camera locations* = 18; Figure 15). In addition, the location of the camera station affected species richness; the cameras closer to residential areas had less species presence (*p* = 0.03; *SE* = 0.26, Figure 15). Species number was not affected by number of human visitors (*p* = 0.5) and distance of the camera station to the highway (*p* = 0.4).

This statistical model explains only some of the variability in species richness, and there are most likely other unmeasured factors at play. For example, we didn't measure light specifically at each camera station. Nighttime light from traffic could be an additional factor affecting number of species.

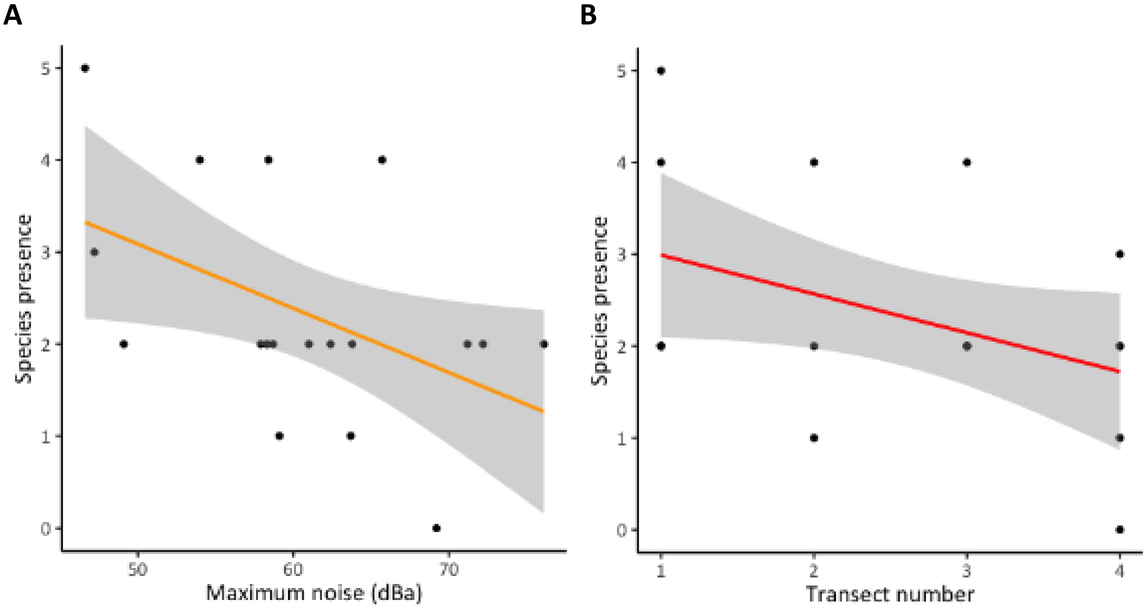


Figure 15. Relationship between species richness and A) maximum noise (dBA) and B) with proximity to residential areas (transect number, higher number = closer to residential).

In terms of individual species, we found that bobcat avoided areas with a higher maximum dBA (*p* = 0.07; *SE* = 0.17; *Z* = -1.8; *n camera locations* = 18), with zero probability of detection common in areas with maximum noise >58 dBA (Figure 16). No clear trend was identified for coyote, deer or striped skunk.

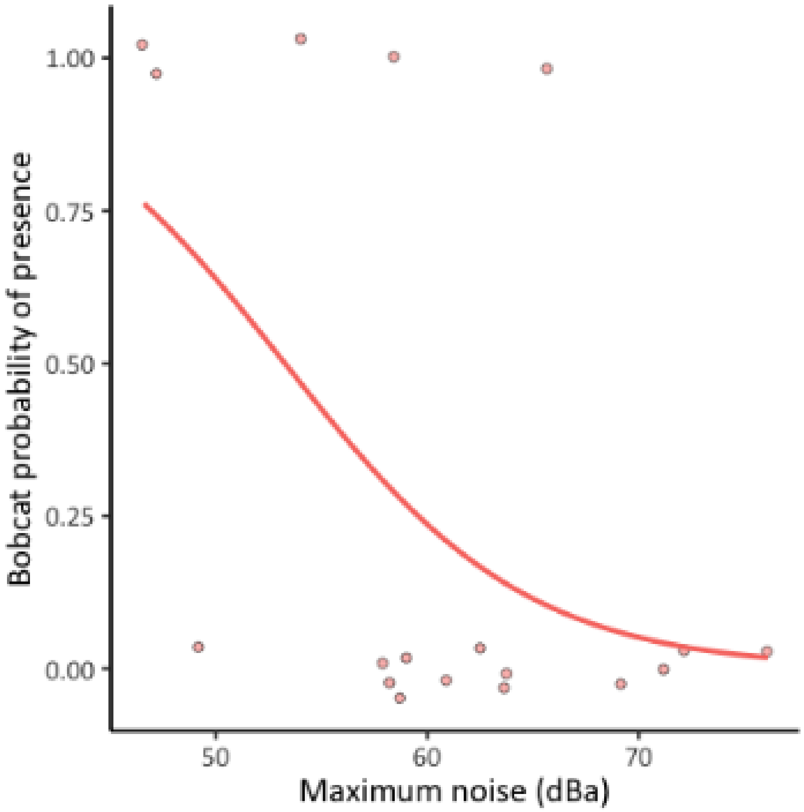


Figure 16. Relationship between bobcat presence and maximum noise (dBA). Red circles represent data from the 18 camera locations, and whether the bobcat was present (probability of presence = 1) or absent (probability of presence = 0).

4. Noise Impact on Species Behavior

Coyote behavior did not measurably alter when exposed to different noise conditions across camera stations within the Liberty Canyon approach zone north of US101 and crossing structures under other highways. However, for deer, the proportion of time spent exhibiting non-vigilant behavior increased at noisy camera stations (15-minute noise recordings, maximum dBA; p = 0.015; SE = 1.8; *n observations* = 28; Figure 17).

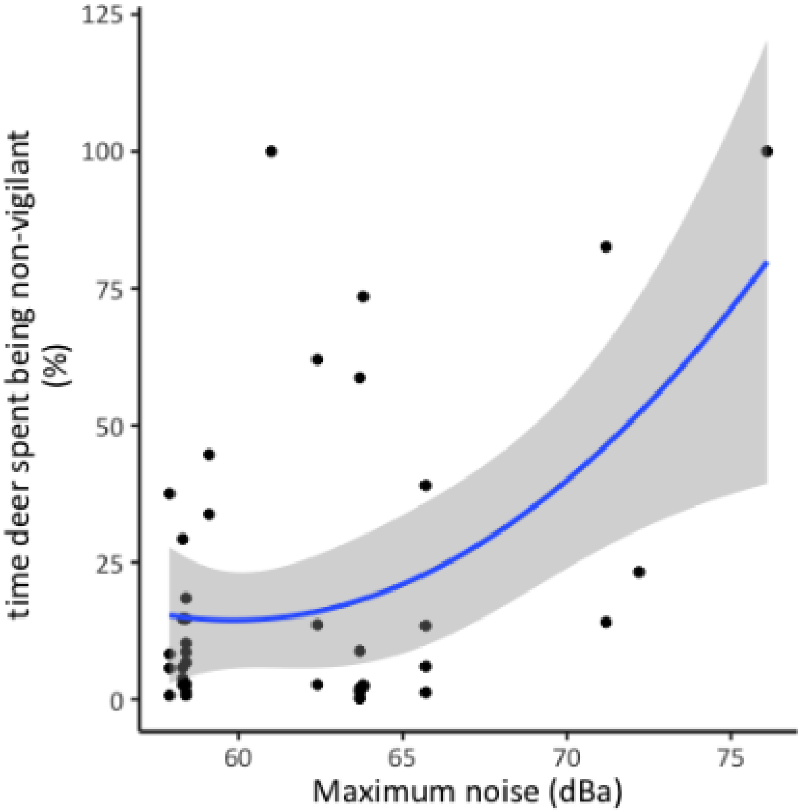


Figure 17. Relationship between deer vigilance and maximum noise (dBA).

For the two crossing structures where behavior of individual animals was analyzed, deer vigilance was greater during exposure to stochastic traffic noise, as opposed to continuous traffic noise ($p > 0.001$) or no traffic noise ($p > 0.001$) at wildlife crossing structures (*n observations = 126;* Figure 18). The mean proportion of total time spent being vigilant during continuous traffic exposure was 0.24 ($Z = -4$; $SE = 0.16$) and during zero traffic was 0.24 ($Z = -6.5$; $SE = 0.17$), whereas the mean proportion of total time during occasional, distinguishable traffic was 0.38 ($Z = -7.5$; $SE = 0.07$).

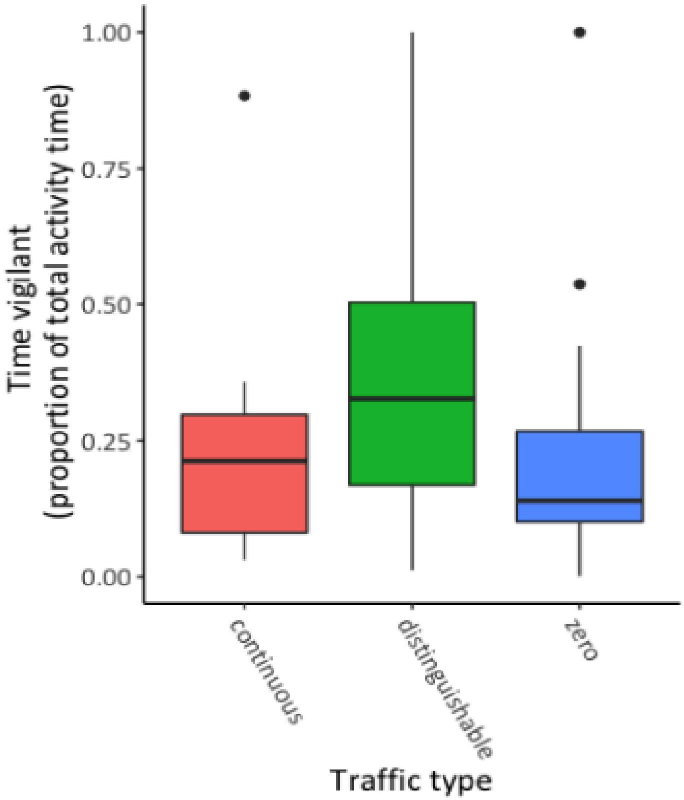


Figure 18. Vigilance under different traffic conditions: continuous, occasional/distinguishable, and zero (no vehicles).

5. Survey of Noise/Light Mitigating Structures

Evaluating and proposing noise abatement strategies to benefit residential areas and wildlife is not new in transportation (e.g., Barrett 1996; Zimmer and Buffington, 1997; Baaj et al., 2001). There is a wide variety of structures intending to mitigate traffic noise and light disturbance of sensitive receptors (e.g., residential areas) near roadways. The most commonly used are walls adjacent to the right-of-way, varying in their materials (e.g., plastic, concrete) and effectiveness. Although these may effectively shield adjacent areas from light (absent stray reflections), noise is notoriously harder to control because of noise reflection, refraction, and vibration of the noise wall itself.

The following are structures that would accomplish the combined job of reducing noise and light propagation from traffic to nearby approach zones at wildlife crossing structures (WCS).

1) Walls: These are the most conventional type of noise abatement structures, which when opaque can also reduce light propagation. WSDOT includes recommendations for noise abatement using noise walls, with a goal of a 10 dB reduction in traffic noise for walls adjacent to roadways (https://www.wsdot.wa.gov/environment/protecting/noise-walls). Noise-reducing walls are often simple concrete structures (Figure 19), though they may also be combined with berms, or vegetation to increase the sound-reduction function (Figure 19).
2) Berms (Figure 19): These can be less-expensive than walls, but that depends on the relative sizes, wall materials, and the structural demands placed by the exact location of the structure. Berms have the benefits of both significantly greater noise reduction and being a vegetated surface and thus more likely to blend into the surrounding terrain. Both of these qualities suggest that this may be the best approach for approaches to wildlife-crossing structures where there is sufficient land within or adjacent to the right-of-way to construct such a structure.

A **B**

C

Figure 19. A) Wall, B) Vegetated wall, and C) Berm.

Discussion

Wildlife connectivity is thought to be improved through the use of wildlife crossing structures (WCS) to convey species across roadways for daily, seasonal/migratory, and genetic connection purposes. Transportation organizations and partner agencies and organizations use WCS, combined with fencing, as the almost exclusive mitigation practice for safety impacts (from wildlife-vehicle collisions) and to reduce the barrier effects of roads/highways.

Traffic Disturbance and Wildlife Presence

As with our previous, smaller-scale project, we found that structures that were built for wildlife crossing and that were opportunistically used by wildlife to cross highways were partially effective at moving species. We found that for 26 sites across California, there were more species in nearby habitat than were observed using the structures. Although we initially thought this was primarily due to traffic noise and light, with a greater "n" of WCS, we found that noise and light disturbance at structures did not explain all of the variation in species presence. In contrast to this general finding, at one site (proposed Liberty Canyon over-crossing) where we studied species presence and activity intensively, species presence was significantly negatively correlated with measured traffic noise. In particular, we found that presence of bobcat was sensitive to a traffic noise level of >58 dBA. Bobcat are one of the target species for connectivity via the proposed Liberty Canyon over-crossing.

Traffic Disturbance and Wildlife Behavior

We found contrasting results for the impact of traffic noise on wildlife activity/behavior. We used vigilance as an important measure of predator-avoidance behavior for mule deer. To avoid predation, deer remain vigilant when they detect a potential threat, which reduces time spent on other important metabolic, reproductive, locomotion, or social behaviors. For deer, as traffic noise increased, the time spent being vigilant decreased, especially above 65 dBA. When deer activity was parsed among WCS with continuous traffic, intermittent traffic, and zero traffic, vigilance was greatest with intermittent or occasional vehicle passage. These results suggest that in the presence of constant and loud traffic, deer are able to be less vigilant, potentially because predators are more sensitive to noise and the risk of predation is lower. These results are consistent with the literature on the human-shield effect of transportation and land-use (Berger 2007; Francis et al. 2009).

Recommendations

1) Thresholds for Effective Use Of WCS

Based on our findings for traffic noise impacts on species presence and behavior, we recommend that a maximum noise threshold of 55 dBA be used to guide design of WCS, or adoption of areas as suitable approach zones for WCS. This threshold is similar to previously-proposed thresholds for significant noise impacts on wildlife (55 dBA, Dooling and Popper, 2007). To maximize diverse wildlife approach and use of WCS, it is worth considering even lower thresholds for areas not immediately adjacent to WCS. This is consistent with Shannon et al. (2016), who showed that wildlife disturbance by anthropogenic noise started at sound levels <50dBA. Light can propagate similarly to noise, but in complex landscapes (such as in the vicinity to the Liberty Canyon over-crossing site), the different ways that noise and light can be absorbed and reflected may result in non-linear relationships between these two traffic-disturbance factors. We found that scalar illuminance levels between 85 and 110 mlux corresponded to a noise level of 58 dBA (Figure 12) and this may be an appropriate conservative light level to use for design of WCS approach zones, at least for larger mammals. This may still be too bright for smaller mammals, which are vulnerable to increased predation when light levels are higher.

2) Structural Mitigation Solutions

Because WCS are a critically-important strategy to improve wildlife connectivity, we initially proposed in the previous project that traffic noise and light conditions at WCS could be improved for structures where light and noise is excessive and reducing wildlife use. Mitigation retrofit/improvements at crossing 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 improvements to existing WCS. For most WCS, it may be enough to erect an earth-filled wall, or similar sound-absorbing structure and achieve a 10 dBA reduction in traffic noise in the vicinity of the approach zones. Approach zones in this case would be defined by the setting and could be >1/2 mile in width along the right-of-way. Walls are also particularly suitable where the right-of-way is not particularly wide. For WCS where a wall may provide insufficient noise reduction and where there is land available, a berm should be considered. It’s much greater noise-reduction, potentially lower cost, and potential to blend into the landscape make it the most attractive of the familiar, disturbance-abatement approaches.

3) Locational Mitigation Solutions

Before a WCS is planned and located within a proposed project, or as its own project, environmental planners can place it so as to minimize potential traffic noise and light disturbance. For example, an under or over-crossing structure in the middle of a long, flat grade (e.g., through a meadow) may be challenging for certain wildlife species to approach because of the long distance that noise and light will propagate without being absorbed by the landscape. Similarly, in areas where slopes face in toward a depressed highway segment, the entire approach zone could be exposed to traffic noise and light and very difficult to mitigate. In contrast, in a nearby area where the approach zone is well below road-grade level, it may be easier or even un-necessary to mitigate noise and light effects because they are less apparent in this part of the landscape. We recommend that consideration of noise and light impacts take place during initial consideration of location of the transportation and mitigation project. This is likely to result in lower costs and need to retrofit WCS later.

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. There is comparatively little guidance for DOTs and their partners for how to design WCS to limit impacts from the immediately adjacent traffic flows.

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. Whatever the justification for the WCS, their effectiveness is assumed during project planning and environmental documentation. This assumption of uniform effectiveness is unrealistic and can reduce the overall benefit of these structures for drivers and biodiversity.

Next Steps

Our results are suggestive of light and noise impacts of traffic on both general wildlife use of WCS and use by individual species of concern. They also indicate that the problem, where and when it occurs, could be mitigated using design of the WCS, use of associated disturbance-abatement structures, design of the approach zone, and placement of the WCS itself. The Road Ecology Center and partners are addressing the first two of these mitigation approaches in the next phase of this multi-project program. In this next project, we are focusing primarily on the proposed Liberty Canyon over-crossing and developing design approaches to reducing traffic disturbance on wildlife approaching the structure. We are also going to focus on other areas that may be instructive for different reasons. For example, the proposed crossing area on I-15 south of Temecula is challenged by having at least one direction of the approach zone being higher-elevation than the roadway, meaning that approaching wildlife would be exposed to the traffic for a long distance.

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Data Management

Products of Research

We collected several primary types of data:

1) Sound measurements at and near highway crossing structures. These were stored as .txt files by the instrument, readable in Excel.
2) Spatial datasets for land cover near crossing structures. These were shared directly with Caltrans.
3) Images and videos from camera traps to measure species presence and behavior. These data collectively represented >70,000 image and video files and >20 GB total size.

Data Format and Content

The sound data files were produced as .txt files readable in Excel. The files included the data/time of the measurement and the measured value. The image files were all .jpg, usable in graphics programs. The images were either of an animal or a "false positive", the product of a trigger event be something other than an animal moving. The images had associated metadata (Exif data) that were used in image processing. The videos were .AVI format, usable in most video software. The videos contained animals, unless the product of a false trigger.

Data Access and Sharing

Data were uploaded to the University of California, Davis's instance of the data repository, Dryad. The node description and ID provided by the Dryad system is: "Understanding Behavioral Responses of Wildlife to Traffic to Improve Mitigation Planning; https://datadryad.org/stash/dataset/doi:10.25338/B87S5G". Because of various limitations of the Dryad system, the image data are available in queryable form here: https://wildlifeobserver.net/projects/noise-and-light-pollution. The map and list query tools in this link allow a user to access data based on the location of field research, or wildlife species.

Reuse and Redistribution

There are no legal limitations on use of the data. The only desired restriction is that we publish the manuscript resulting from the project before the data are used elsewhere. Data can be reused and redistributed with credit to this report and referencing the above DOIs. Suggested citation:

> Shilling, Fraser (2020), Understanding Behavioral Responses of Wildlife to Traffic to Improve Mitigation Planning, v2, UC Davis, Dataset, https://doi.org/10.25338/B87S5G
>
> Shilling, Fraser, and David Waetjen. Wildlife Observer Network: Noise and Light Pollution. https://wildlifeobserver.net/projects/noise-and-light-pollution