Performance of a Freeway Underpass as a Regional Wildland Linkage for Mammals

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Table of Contents

Table of Figures:

Abstract

Anthropogenic development, particularly roads and highways, acts as a barrier and leads to fragmentation of wildlands. Wildlife corridors such as the Los Piñetos underpass beneath State Route 14 in Santa Clarita, California offer a linkage between wildland habitats. A 2011 UCLA Environmental Science practicum installed camera traps to investigate wildlife activity in and around the underpass. Our research built upon this dataset, and we used a data analysis program to electronically analyze over 50,000 photos taken since March 2011. The program provided statistical outputs such as species activity patterns and species similarity comparisons which were exported to Microsoft Excel. The photos captured species including: mule deer, gray fox, raccoon, skunk, bobcat, coyote, mountain lion, and badger. We also installed four additional cameras to investigate why mule deer were not recorded using the underpass, and why gray fox are rarely recorded using the underpass. Deer are relatively abundant in the area and were spotted in locations close to the underpass, but never inside the underpass. We calculated density estimations of deer and fox to gain insight into their local distribution. Although activity times of mule deer were temporally segregated from human activity, they were not geographically segregated, arguing against human activity precluding deer use of the underpass. We concluded that deer are likely absent in the underpass due to lack of funneling fencing or "V" shaped topography, lack of vegetation cover, or loud noise levels due to traffic. We calculated that gray fox are very rare in the area relative to other species, concluding that they are using the underpass in proportion to their estimated species density.

I. Introduction

Coastal Southern California is an area of extensive urban sprawl, and as a consequence local wildlife is faced with habitat loss and fragmentation (Ng et al. 2004). Roads, especially highways, present a threat to wildlife survival by reducing available habitat, increasing erosion of habitat due to storm runoff, fragmenting populations, and preventing movement of wildlife to better habitat (Jackson et al. 1999). These negative effects may be mitigated by the presence of underpasses, which provide connectivity by allowing safe movement across barriers. Certain factors of an underpass may increase its effectiveness, including size, vegetation, and frequency of use by humans. These factors must be studied in relation to the preferences of nearby wildlife in order to maximize use by animals and ensure that the underpass serves its desired purpose.

Species native to Southern California for which underpasses may be valuable migration tools include the California mule deer (*Odocoileus hemionus californicus*), gray fox (*Urocyon cinereoargenteus*), mountain lion (*Puma concolor*), American badger (*Taxidea taxus),* bobcat (*Lynx rufus*), and coyote (*Canis latrans*). Additional native species of importance include mid-size mesopredators such as the striped skunk (*Mephitis mephitis*) and raccoon (*Procyon lotor*), though little is currently known regarding their use of underpasses. In the presence of human settlements, mule deer tend to experience habitat fragmentation, defensive behaviors, road kill, and food scarcity (Reed et al. 1975). Gray fox are also negatively affected by both proximity and intensity of urbanization (Ordeñana et al. 2010) and have a tendency to avoid roads (Markovchick-Nicholls et al. 2008), making culverts or corridors an important means of dispersal. The small average population densities of both the mountain lion and the American badger create a need for habitat connectivity in order for species to mate, maintain a diverse gene pool, and, in the case of the mountain lion, maintain their large home ranges (Beier 1995, Ordeñana et al. 2010). Development is of special interest with relation to the American badger, which is listed by the California Department of Fish and Wildlife as a “species of special concern,” meaning that the ecological impact of development on badgers must be considered in areas of urban expansion (Quinn 2007). Bobcats and coyotes are better able to utilize underpasses and other habitat connections than other species and are relatively less threatened by habitat interruption (Lehner 1976, Ordeñana et al. 2010, Ruell et al. 2012), making them ideal indicator species.

Both mule deer and gray fox require plentiful vegetation and overhead cover in order to transverse an area, as they are likely to be hunted in open spaces (Pierce et al. 2004, Ordeñana et al. 2010, Farias et al. 2005). Similarly, both species, especially mule deer, prefer wide and open corridors (Reed et al. 1975, Gordon and Anderson 2003, Donaldson 2005, Girlo et al. 2008). Preference for larger corridors could result from fear of predation or becoming easily trapped in a narrow space. Coyotes pose the greatest intra-guild threat to gray fox survival in Southern California (Fedriani et al. 2000). Mule deer are preyed upon by coyotes, bobcats, and mountain lions (Pierce et al. 2004). Clevenger and Waltho (2000) found that deer and most other species were reluctant to cross an underpass in close proximity to a town or development. Rost and Bailey (1979) claim that increased traffic volume can cause deer to fear an underpass or its surrounding area. Nicholson et al. (1997) confirms that deer steer clear of humans and human development whenever feasible. Bobcats and coyotes are less affected by presence of humans and act more as predators than prey within their ecosystems, and are thus more easily able to navigate corridors (Lehner 1976, Ordeñana et al. 2010, Ruell et al. 2012). Bobcats are not hesitant to explore new infrastructure, utilizing bridges and vegetation pathways in areas separated by highways (Ventura 2003). Mountain lions have been shown to use underpasses for dispersal, but avoid areas with artificial lighting and obvious human activity. Artificial lighting is especially deterrent in open habitats, some woody vegetation is therefore recommended to provide cover (Beier 1995). There is little information available regarding the behavior of the American badger in conjunction with underpasses. Grilo et al. (2008) found that the European badger is significantly more likely to use corridors which are at least 500 meters away from other roads and are absent of human activity.

A thorough understanding of how these species interact with local underpasses is important to preserve connectivity and to enhance conservation management guidelines in Southern California and other similar habitats. We studied the use of an important underpass that is thought to provide regional connectivity by native mammals in Southern California. Our study spanned several years and concerned multiple species. We estimated underpass use with camera traps and calculated home range, relationships with other species, and temporal and spatial changes in abundance. Our goals were to determine why certain species are more likely to use the underpass than others and to develop an idea of how human underpass use may be affecting that of local mammals. With this information we hope to provide conservation management guidelines which will mitigate the effects of habitat fragmentation in an urbanized area.

II. Methods

Study Area

Species migration through the Los Piñetos underpass in Santa Clarita, Southern California has been monitored in recent years for the movement of large mammals and mesopredators. Santa Clarita is just outside of Los Angeles, Ca, about 40 km north of the UCLA campus (Figure 1a). This underpass is located beneath SR-14 between Elsmere Canyon Protected Open Space, owned by the Mountains Recreation and Conservation Authority (MRCA) on the east, and the City of Santa Clarita's Gate-King Protected Open Space on the west, which is located in the Newhall Wedge. Within the Newhall Wedge, a small triangular plot of privately owned land separates SR-14 and a major traffic thoroughfare, Sierra Highway (Figure 1b). The surrounding vegetation consists of California sage scrub, chaparral, and some isolated oak woodlands (Figure 2). The study site is restricted to public vehicles with a locked metal gate. A series of hiking trails within Elsmere Canyon Open Space are open to the public and frequented by hikers on foot, bikers, horseback riders, and domestic dogs. Also, a series of bridges are located along the SR-14 where Sierra Highway crosses under the freeway, 1.3 km away from the Los Piñetos underpass.

In 1993, environmental consultants predicted that the Los Piñetos underpass would be the most used wildlife crossing under SR-14, and therefore was integral to habitat connectivity between the San Gabriel Mountains and the Newhall Wedge (Gate King EIR 2003). Private land adjacent to the underpass and between these two protected land areas may be developed within the next few years, jeopardizing this connection (Gate King EIR 2003, Freidin et al. 2011).

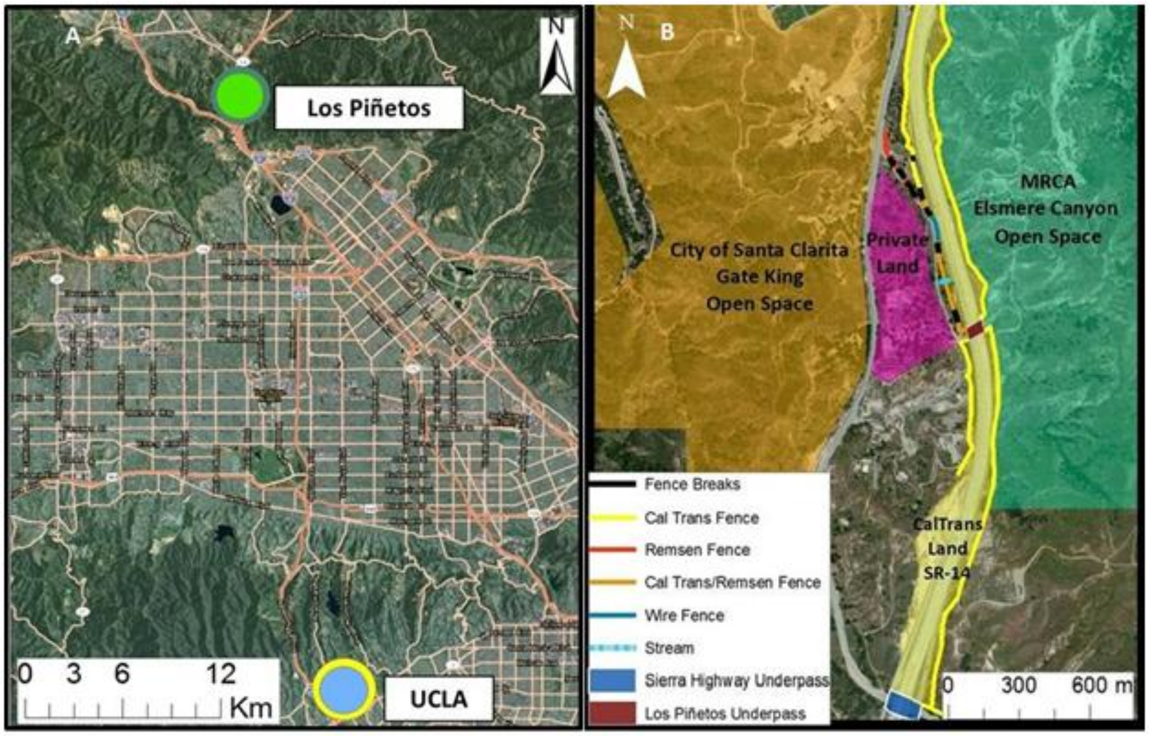

Figure 1 (left) Aerial view of Northern Los Angeles depicting the relative distance between UCLA and the Los Piñetos underpass. (right) Aerial view of the study site, including land ownership and fencing.

Figure 2: Photo and dimensions of the Los Piñetos underpass and SR-14 facing west.

Camera Trap Data

In March 2011 the first cameras for this project were installed and maintained by a previous UCLA Environmental Science Practicum group, who reported their findings in 2011 (Freidin et al. 2011). The initial cameras used were 3-megapixel Cuddeback Expert Digital Scouting Camera C3300 (flash), most of which were subsequently switched to 12-megapixel LTL Acorn Scouting Camera (infrared) due to the potential activity disturbance by a “flash” camera. From June 2011 to January 2013 the cameras were monitored and data was collected by Dr. Boydston of United States Geological Survey (USGS) and colleagues. Beginning January 2013, we took over data collection.

The preliminary part of our project consisted of analyzing photos taken since March 2011. Photos were first transferred from SD cards (1, 2, or 4 GB) to a computer via a Transcend Internal multi-card Reader, then downloaded on a 500 GB external hard-drive and distributed to each group member. Photos were sorted by all members on personal computers, by camera, species, and number of subjects (Appendix A1). Photos of humans were sorted according to the human’s mode of transportation (i.e. human on foot, biker, vehicle). Photos with multiple classifications, i.e. humans with dog(s), were duplicated and placed into a folder labeled “human_on_foot” as well as “CAFA_domesticdog.” Photos with no meaningful subjects were abundant and were placed in a folder labeled “Other.” Photos with unidentifiable subjects were placed into a folder labeled “Unknown.” To eliminate counting the same individual twice, photos captured within 60 seconds of a previous photo were eliminated from the working dataset and kept for storage in a separate dataset. This purpose of this decision was to create consistency since Cuddeback cameras were capable of taking only one photograph per 60 seconds.

Monitoring Existing Camera Stations

Camera sites were checked every one to three weeks to retrieve data and monitor conditions of the cameras. During each field visit, we removed memory cards from cameras and downloaded photos onto the 500 GB external hard-drive for data analysis. To avoid excessive false triggers at locations with extensive vegetation, we manually removed vegetation within the camera’s sensing range. Each camera was assigned a letter and number depending on where it was installed (Table 1).

Table 1: Simplified camera naming conventions and camera list.

Location	Name	Cameras
In the underpass	U	U1, U2, U3, U4
Close to the underpass	C	C1, C2, C3, C4
Far from the underpass	F	F1, F2, F3
On Remsen St.	R	R1, R2, R3

New Camera Installation

After evaluating the study site, we installed four additional cameras to get better coverage of the study area and acquire a broader dataset. Three of these locations were chosen along Remsen St. on the west side of SR-14, an area where there was no previous data collection. These cameras were tagged as “R” cameras. The fourth was installed in the underpass, a “U” camera. These new cameras were installed in addition to other existing and retired cameras installed by the previous practicum group (Figure 3).

Camera R1 was installed at a large break in the Caltrans-owned fence in hopes of detecting animals that may pass through the break to cross the freeway. This camera is located approximately 30 m from the freeway. R2 was installed on the boundary between Santa Clarita owned land and Caltrans owned land. It was pointed toward a small 1 m diameter metal culvert which goes straight through the freeway, to detect animals that may be using this route as an alternative to the underpass. R3 was installed along Remsen St. in an area characterized by an oak woodland/riparian habitat with a small intermittent stream. It was positioned facing the road because we intended to detect animals on the west side of the freeway, a previously unmonitored area. U4 was installed in the northeast corner of the underpass to achieve more comprehensive photo coverage of the underpass.

To install the cameras, square metals posts (7.6 cm wide, 1.5 m tall, holes every 5 cm) were pounded into the ground. Cameras were mounted onto the metal post at approximately knee height using screws and bolts. All cameras were placed in a metal box secured with a padlock. All newly installed cameras were 12-megapixel LTL Acorn scouting cameras with infrared motion sensors. The diameter of detection of the LTL Acorn cameras was tested using a tape measure and human subjects and found to be 20 meters.

Specifications for individual cameras varied greatly depending on the camera type, surrounding vegetation, and human presence. (Appendix A2). Cameras that were in the underpass or close to the underpass were set to normal sensitivity. Cameras in sunny or densely vegetated areas were set to low sensitivity to avoid excessive false triggers. The camera's side-sensors were turned off. We avoided installing cameras in an easterly or westerly facing direction to prevent false triggers due to the movement of the sun (Appendix A3).

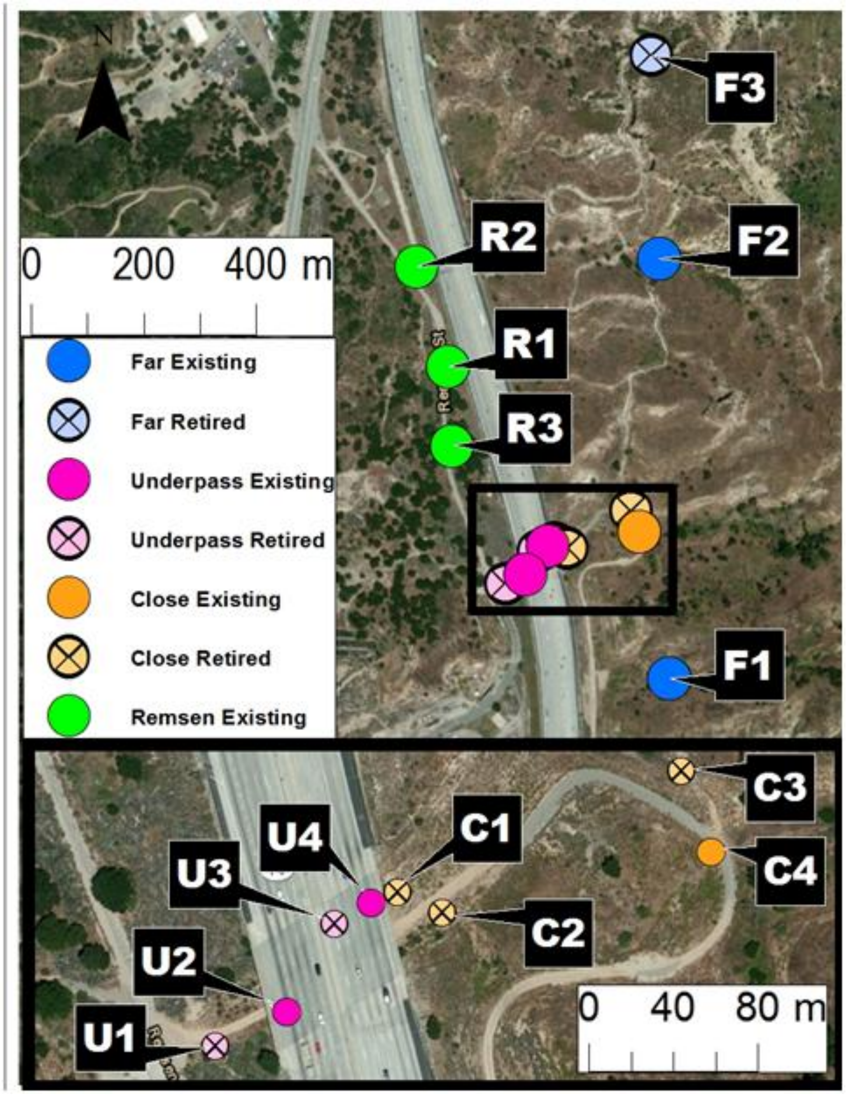

Figure 3: Aerial map of locations for all cameras used in the study.

Photograph Analysis Software

We used a camera trap photo analysis computer program (which we will now refer to as "SmallCats") to analyze photos. The program was developed by Dr. Jim Sanderson (founder of the Small Cat Conservation Alliance) specifically for use with camera trap photos, sorted by species-type (including humans and vehicles as their own respective categories). Seasonal patterns, similarities between species, species diversity, and species accumulation curves were analyzed using this software as well as other appropriate analysis trends. Graphs were created using SmallCats in conjunction with Microsoft Excel. Additionally, the SmallCats software calculated temporal similarity per species pair. Output numbers ranged from zero to one, with lower numbers representing more similar pairs.

SmallCats is a collection of several distinct programs that were created to enhance photo data analysis. These programs include "ReNamer," "DataOrganize," and "DataAnalysis." ReNamer is used to create a unanimous naming and dating convention for all the photo files, as the default dating formats of Cuddeback cameras and LTL Acorn cameras are different. All photos are re-named consistently with the year, month, day, and time to the second. DataOrganize creates a numerical and categorical text file of all the photo files based on the hierarchical structure of file folders. The text file that DataOrganize generated can then be imported to DataAnalysis which creates preliminary statistical analysis. The output text files generated in this process can be converted to an Excel spreadsheet for further statistical tests.

Noise Pollution Data Analysis

Sound levels were measured at each camera station using the iPhone application "NoiseHunter." A 30 second sample of noise data was collected in one day between the hours of 11:00 am to 1:00 pm to obtain relative levels of noise pollution at each camera station. Data were collected with an iPhone 4S held vertically with the microphone facing up.

Road kill Data Analysis

We attempted to contact Caltrans, and researched UC Davis's Road Ecology Center's database (Shilling et al. 2013) to obtain records of road kill along SR-14 to determine if mule deer, gray fox, or other species have been found deceased near the study site. No road kill records were available in or near the study site and very limited relevant road kill records were available for the nearby areas.

Study Site Mapping

Fence breaks were physically scouted in the field and recorded using a Garmin eTrex Vista HCx GPS unit. Fences in the study area were mapped using ArcGIS and Google Earth. Openings in the fence that may serve as an easy transversal pathway for animals were mapped and integrated into the GIS map.

GPS coordinates were taken in the field at each camera station. GPS data was entered into ArcGIS to create a map of the study site for analysis.

Statistical Analysis

Linear Regression Analysis for Spatial Patterns

The number of individuals of one species at each camera location was divided by the total number of trap nights for that camera, obtaining an average number of individuals per trap night per location. Trap rates for species pairs of interest were then plotted against each other in a scatterplot, and linear regression analysis was done for each plot. Pairs of interest were gray fox and coyote, as intraguild competition and coyote dominance could be minimizing use of the underpass by gray fox (Fedriani et al. 2000, Farias et al. 2012); and mule deer and humans, since mule deer are particularly sensitive to human presence (Reed et al. 1975, Vogel 1989, Sommer et al. 2007). The coefficient of determination, R^2, was then used to measure how well the trap rate per location of one species predicted that of another. Essentially this value was used to determine whether the occurrence of two species was correlated by location.

Circular Statistics for Temporal Analysis

Daily temporal activity patterns (0:00 to 24:00 hours) for each species were determined with the SmallCats software. The hourly activity data (given as number of pictures per hour interval) was plotted on a radar graph from which species comparisons could be made. Using circular statistics, the mean direction of each data set was determined and plotted on the respective graphs. The mean direction line represents both the average time that a particular species was active (given by the angle of the line) as well as the strength at which said line portrays the true mean direction of the graph (given by the length of the line).

The statistical mean direction of each plot (shown as a straight line on the plot) was calculated as follows:

$$X = \frac{\sum_{i=1}^{n} \cos_a}{n} \qquad Y = \frac{\sum_{i=1}^{n} \sin_a}{n}$$

$$r = \sqrt{X^2 + Y^2}$$

$$\cos \bar{a} = \frac{X}{r} \qquad \sin \bar{a} = \frac{Y}{r} \qquad \theta_r = \arctan\left(\frac{\sin \bar{a}}{\cos \bar{a}}\right)$$

In the equations above, “n” is the total number of pictures, “a” is the location on the graph in degrees (i.e. 0:00 = 0 degrees), “X” and “Y” are the rectangular coordinates of the mean angle, and “r” is the mean vector. Once obtained, the Rayleigh z test was performed for each species to determine the significance of the calculated mean direction. Given the null hypothesis that there is no sample mean direction, an alpha value of 0.05 (similar to p value) was chosen, and $Z=nr^2$ was calculated. A Z score above the critical value given in a Rayleigh Z Score chart corresponding to an alpha of 0.05 means that we reject the null, and that there is a mean direction for each radar graph (Zar 1995).

The Watson U^2 test was used to statistically test the similarity of the temporal activity patterns of our comparative species of interest (fox vs. coyote, mule deer vs. humans). Specifically, the Watson U^2 allows rejection/acceptance of the null hypothesis that the two sets of data are not significantly different. The equation is as follows:

$$\mathrm{U}^2 = \frac{(\mathrm{n}_1\mathrm{n}_2)}{N} \times \left(\sum \mathrm{t}_\mathrm{k}\mathrm{d}_\mathrm{k}{}^2 - \frac{\sum (\mathrm{t}_\mathrm{k}\mathrm{d}_\mathrm{k})^2}{N}\right) \text{where } \mathrm{d}_\mathrm{k} = (\mathrm{m}_{1\mathrm{i}}/\mathrm{n}_1) - (\mathrm{m}_{2\mathrm{j}}/\mathrm{n}_2)$$

M represents the sequentially summed number of photos in each time interval. N represents the total number of observations (photos of each respective species). T_K represents the total number of species (species a plus species b) in a certain time interval (Zar 1995).

Once obtained the U^2 value is compared to a master chart containing p values vs. n. If above the given U^2 value on the chart, the null observation is to be rejected. If below, the null cannot be rejected (Zar 1995). We used a p value of 0.05 for the chart comparison.

Density Study and Underpass Transversal

The very low photo trap rate of gray fox leads us to hypothesize that the reason why fox were rarely captured using the Los Piñetos underpass is due to their small population density. In addition, we hypothesized that mule defer absence in the underpass is not proportional to their population density. To examine this, we used a formula for estimating animal density that did not require distinction of individuals (Rowcliffe et al. 2008). The formula includes the following variables: a) radius of detection of the camera, b) angle of detection of the camera, c) camera trap rate per unit time, d) species' daily range of movement (which was estimated from other sources), and e) average group size of the particular species. The formula for density is (Rowcliffe et al. 2008):

$$D = \frac{y}{t}\frac{\pi}{vr(2+\theta)}$$

Component y/t represents camera trap rate of species in question; v represents velocity (daily range) of species in question; r represents radius of the camera's zone of detection; θ represents the angle of the camera's detection zone.

To examine the sensitivity of the formula with respect to the animals' daily range of movement, we used a range of daily movement data from several sources. The data that was most relevant to our species and habitat-type was used to create an estimate of density with error bars showing conservative estimates and high estimates.

III. Results

The first cameras were installed March 6, 2011. The last cameras were uninstalled May 11, 2013. Overall, 14 cameras were used throughout the study for a total of 3,684 camera trap days. Out of over 50,000 photos taken, there were 10,583 photos taken with subjects in them; the remaining 40,000+ photos were false triggers (Figure 4, Figure 5).

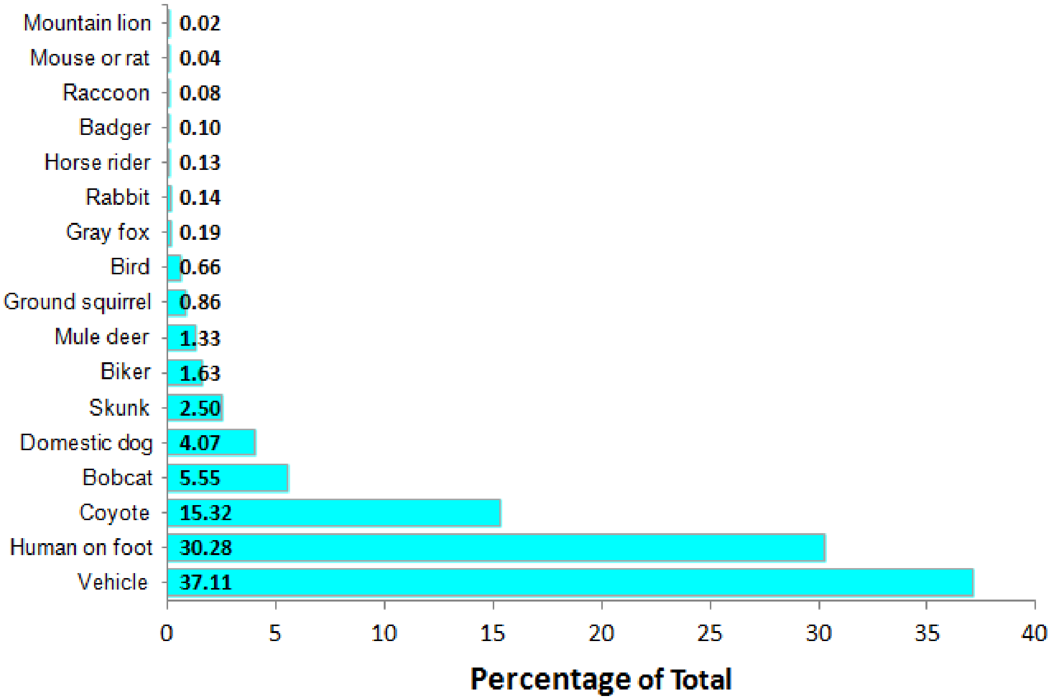

Figure 4: Percent total of all photos for all subjects recorded at and near Los Piñetos underpass, March 2011–May 2013 (n=10,583).

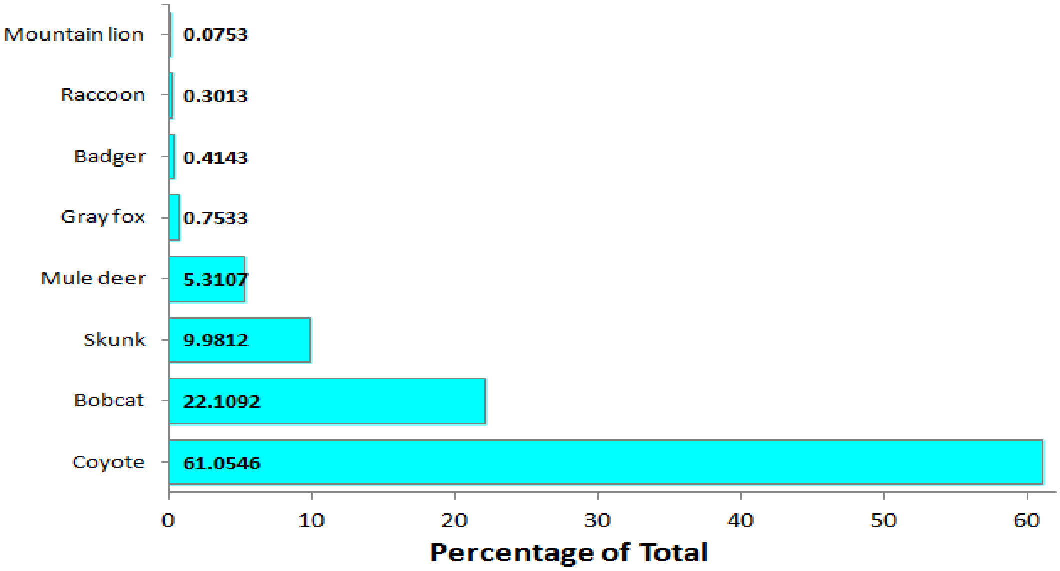

Figure 5: Eight mammalian species of interest organized by percent total at and near Los Piñetos underpass, March 2011–May 2013 (n=2,655).

Species Accumulation

Species accumulation curves illustrating the number of species found at cameras C4, U2, F1, and F2 were created to determine whether a difference in the amount of species at close, underpass, and far cameras existed. Curves were created for these four cameras only because they have been running for the longest amount of time and therefore provide sufficient data to construct meaningful species accumulation curves. Species accumulation rates differed between the C and U camera, revealing that more species were present at the opening of the underpass and fewer species were actually present in the underpass. Animals were coming close to the underpass, but not going through (Figure 6).

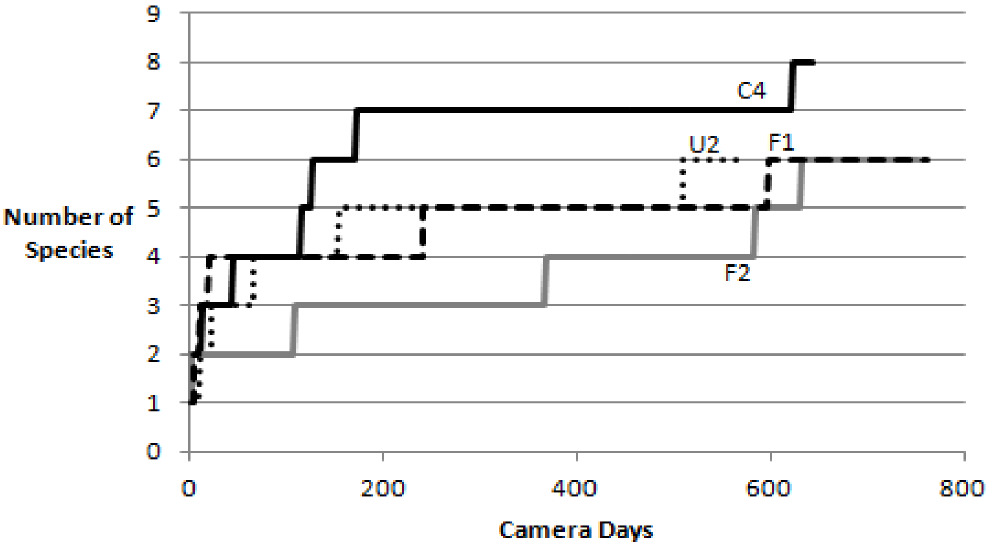

Figure 6: Species accumulation at cameras example cameras close (C4), under (U2), and far (F1, F2) from the Los Piñetos underpass, March 2011–May 2013.

Spatial Patterns

We looked at spatial correlations between coyote and gray fox (a) and between humans and mule deer (b), as these are the pairs thought to be influencing each other (Figure 7). We found that neither species pair is spatially correlated (R^2 = 0.0416 for mule deer and humans; R^2 = 0.0045 for gray fox and coyote). Thus, there is no clear difference in the frequency or number of sites visited by humans as opposed to mule deer, nor for coyote and gray fox.

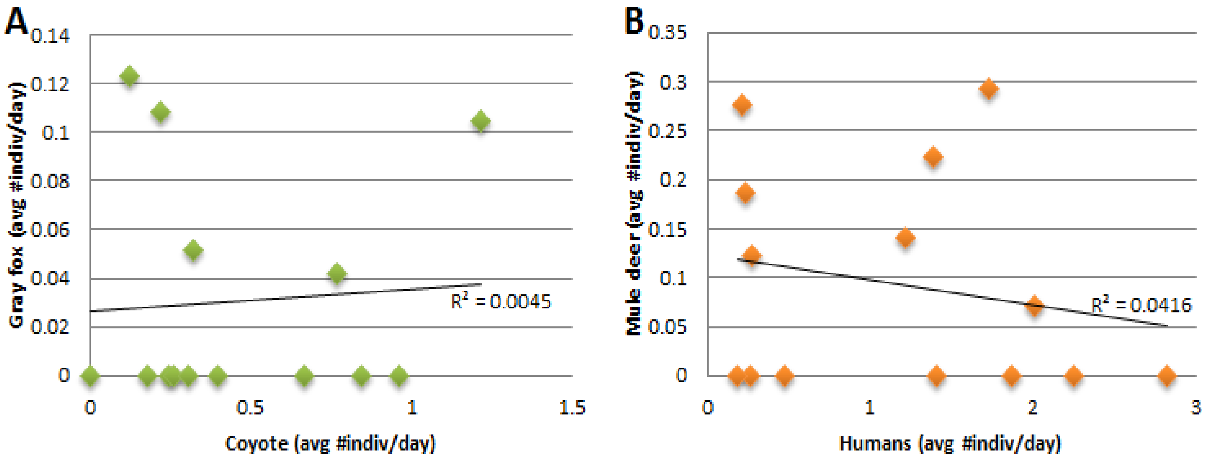

Figure 7: Species Pairs Trap Rates for (A) coyote and gray fox and (B) humans and mule deer, calculated using total number of individuals by total number of trap nights per camera.

Temporal Patterns

Comparing the graphs for humans and mule deer, the data showed strong temporal contrast, with humans active during daylight hours and mule deer active throughout the night (Figure 8A,B). The comparison between gray fox and coyote revealed temporal similarity, with both species active during nighttime hours (Figure 8C,D).

For the comparison of deer and human temporal data, the Watson U^2 test (Calculated $U^2 >$ Reference U^2) (Figure 8) leads to the conclusion that deer and humans are temporally different from a statistical standpoint. Regarding the comparison of coyote and fox, the Watson U^2 test (Calculated $U^2 <$ Reference U^2) shows that the species are not temporally different from a statistical standpoint. As seen in the radar graphs, there is temporal niche partitioning between humans and other species.

Temporal similarity indices from the SmallCats software also demonstrate species pair relationships (Table 3). The index for gray fox and coyote was 0.029, since they are active at similar times of night, and the indices for mule deer and different manifestations of human presence (hikers, vehicles, and bikes) ranged from 0.084 to 0.095.

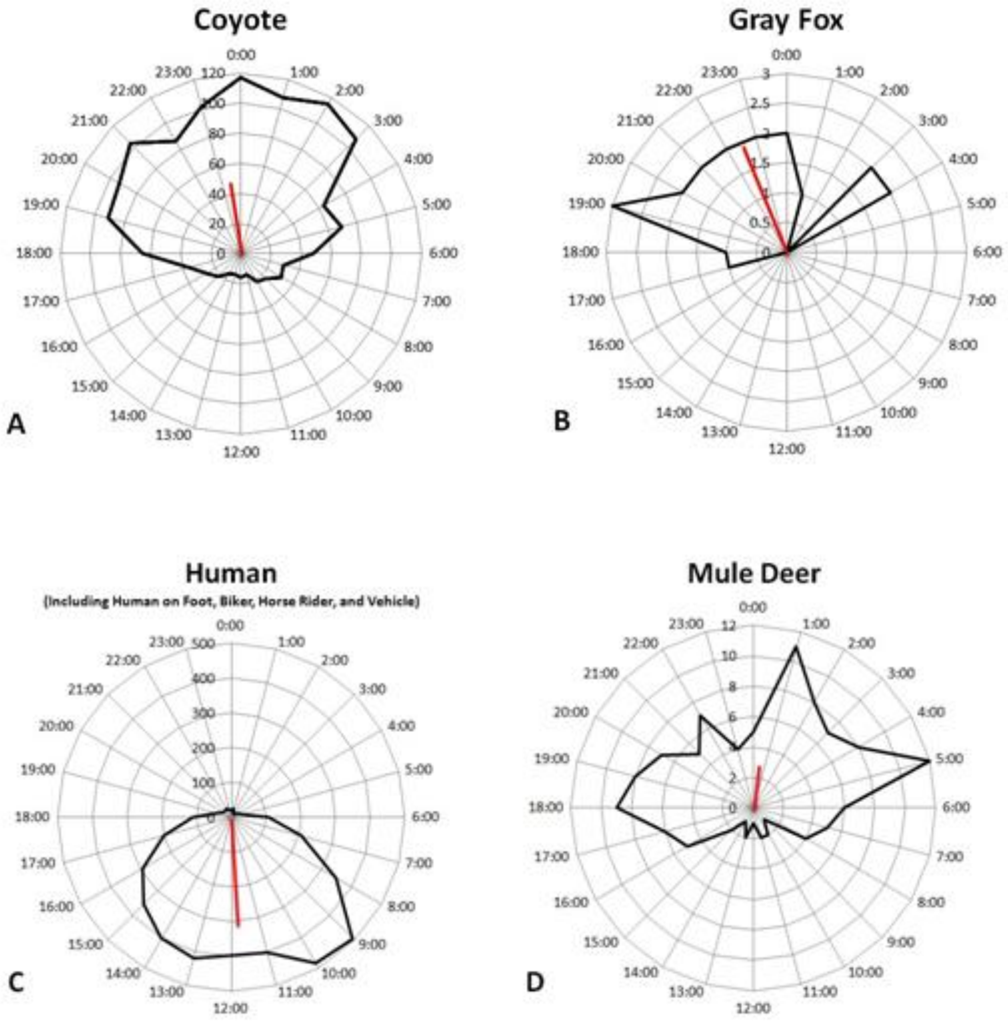

Figure 8: Temporal activity radar graphs, including statistical mean direction vector - (A) Coyote, N = 1413, R = 0.433 ; (B) Gray Fox, N = 20, R = 0.673 ; (C) Human, N = 4490, R = 0.629; (D) Mule Deer, N = 128, R = 0.528. Data collected at the Los Piñetos underpass, Santa Clarita, California, March 2011–May 2013.

Table 2: Watson U^2 values for Deer versus Humans and Coyote versus Gray Fox temporal activity similarity. H_0 is that the data in comparison is not significantly different. Data obtained from Figure 8.

Comparison	**Calculated U^2**	**Reference U^2**	**H_0**
Deer vs. Humans	5.692	0.1869	Rejected
Coyote vs. Gray Fox	0.103	0.1869	Not Rejected

Table 3: Similarity Index Chart for Species Pairs of Interest

	Bobcat	Mule Deer	Gray Fox	Human	Vehicle	Biker
Coyote	0.006	0.01	0.029	0.105	0.096	0.113
Bobcat	-	0.022	0.026	0.134	0.127	0.142
Mule Deer	-	-	0.049	0.095	0.084	0.095
Gray Fox	-	-	-	0.166	0.161	0.176
Human	-	-	-	-	0.01	0.014
Vehicle	-	-	-	-	-	0.021

Seasonal Patterns

Seasonal monthly patterns of coyote, bobcat, mule deer, gray fox, and human were graphed using the SmallCats software. The large carnivores, coyote and bobcat, are generally active the same amount year-round with a slight increase in activity in the autumn months. Mule deer are far more active in August through November. Gray fox have a very large peak in activity in winter, mainly in December. Human presence is consistent throughout the year with a small peak in the cooler Southern California autumn and winter months, and lower activity in summer, when it may be too hot to go hiking (Figure 9).

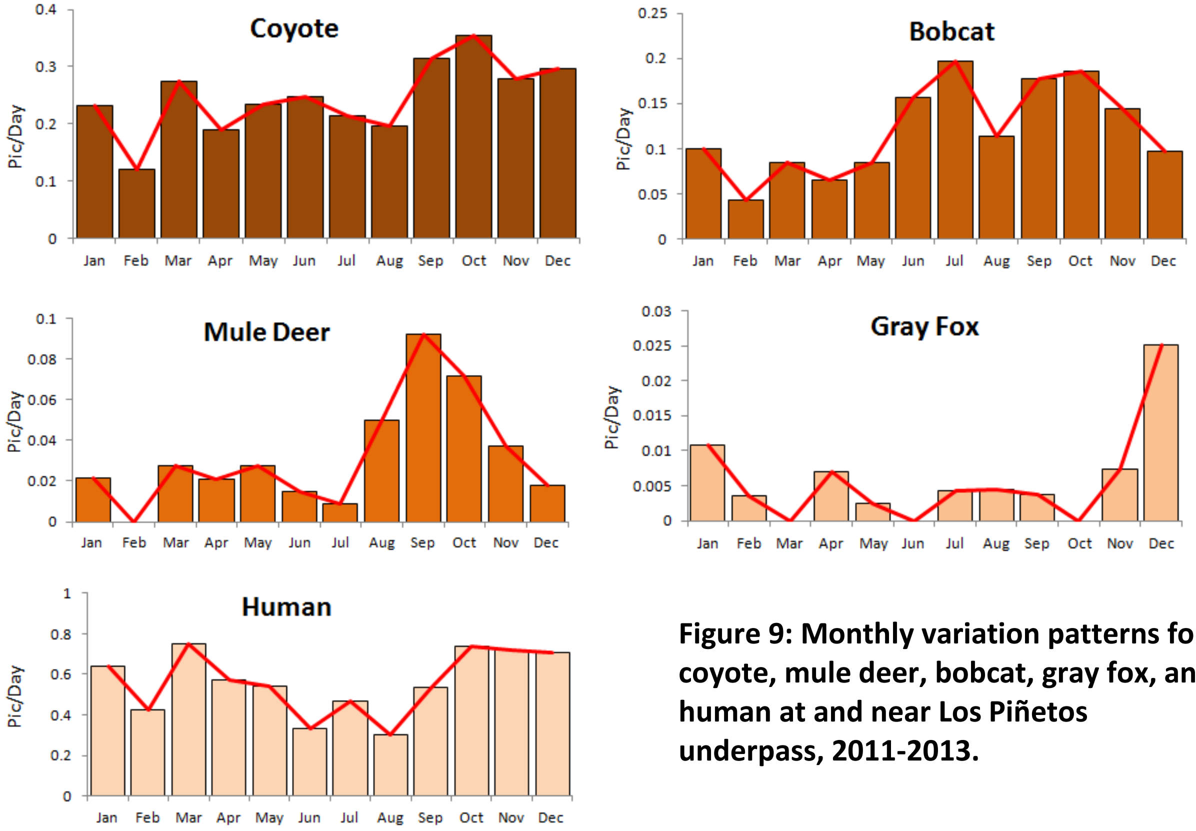

Figure 9: Monthly variation patterns for coyote, mule deer, bobcat, gray fox, and human at and near Los Piñetos underpass, 2011-2013.

Alternative Routes Across Freeway

After the fence break GPS points were mapped, we noticed several fence breaks on the west side of the freeway that may be large enough for animals to transverse (Appendix A4). We found no large fence breaks on the east side of the freeway. Both coyote and skunk were photographed going through a large break in the Caltrans owned fence at camera R1 (Figure 10A).There are at least two large 1 m diameter metal culverts that may be large enough for animals to transverse. One such instance of a coyote entering the metal culvert was captured with camera R2 (Figure 10B).

Figure 10: (A) Coyote walking through a fence break in the Caltrans Fence at camera R1. (B) Coyote entering a metal culvert beneath SR-14 at camera R2.

Directionality of Movement

We surveyed the directionality of the animal subjects in the underpass to determine whether or not a majority of them were going eastward toward Elsmere Canyon Open Space, or westward toward the Gate King Open Space. The results for this survey were inconclusive, as 46% of subjects were westbound, 51% eastbound and 3% unknown direction. No individual species demonstrated a strong majority for a specific directionality (Appendix A5).

Noise Levels

Generally, if the camera was further from the freeway, a higher average decibel reading was recorded. Sound readings are heavily affected by local topography. A downhill slope will have a lower decibel reading when compared to a flat or uphill slope. The “R” cameras had the highest sound readings. The “U” cameras directly under the underpass were quieter due to the muffling effect of the tunnel. The “C” and “F” cameras were the quietest due to their distance from the freeway (Appendix A6).

Density Study

An estimate of population density was obtained for fox, deer, and coyote using a formula derived by Rowcliffe et al. (2008) and day range data from several sources (Table 4). The median estimates for density (individuals/km^2) were: Coyote: 4.932; Deer: 0.885; Fox:

0.131. The results indicate that coyotes are 37.64 times more abundant than gray fox, and deer were 6.76 times more abundant than gray fox (Figure 11).

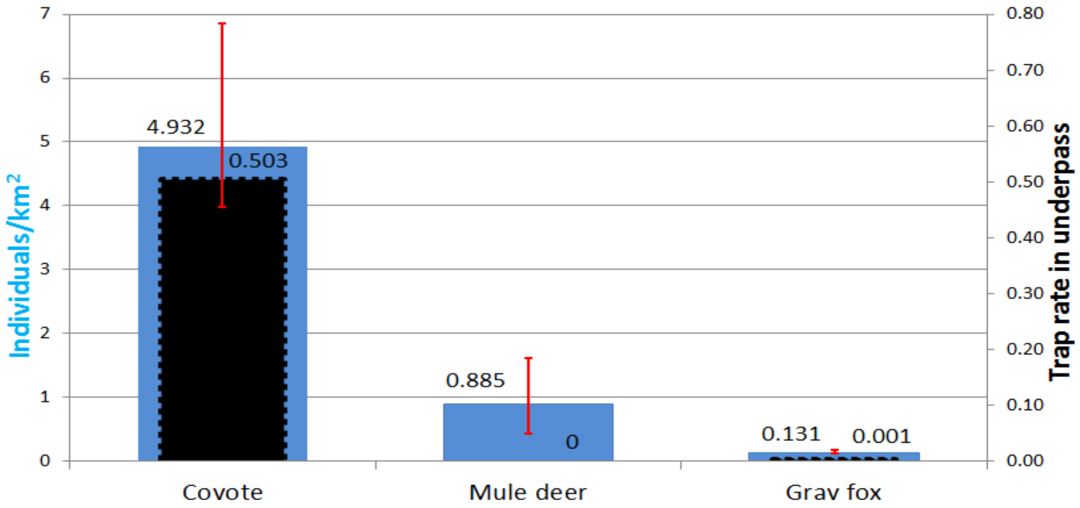

Figure 11: Left axis represents species density estimated from formula derived by Rowcliffe et al. (2008). Right axis represents underpass trap rate (photos/day). Error bars display high and low and estimates using various day range data.

Table 4: Estimated densities based on day range data from various sources

Species: Coyote	**Coyote density (km^{-2})**	**Day range (km/day)**	**Source**
Low estimate	3.971	6.9	Carbone et al., 2001
Median estimate	4.932	5.556	Grubbs & Krausman, 2009
High estimate	6.851	4	Vu, 2011
Species: Mule Deer	**Deer density (km^{-2})**	**Day range (km/day)**	**Source**
Low estimate	0.427	5.7	Feldhamer et al., 2003
Median estimate	0.885	2.75	Carbone et al., 2001

High estimate	1.622	1.5	Feldhamer et al., 2003
Species: Gray Fox	**Fox density (km^{-2})**	**Day range (km/day)**	**Source**
Low estimate	0.121	2.7	Feldhamer et al., 2003
Median estimate	0.131	2.5	Carbone et al., 2001
High estimate	0.172	1.9	Feldhamer et al., 2003

IV. Discussion

The results of our data analysis lead us to several surprising conclusions. We hypothesized that the lack of deer in the underpass was due to human activities. Species activity radar graphs show that deer are mostly active at night when human presence is naturally at the lowest. Temporal niche partitioning was evident in species activity patterns. This partitioning suggests that the reason deer are not using the underpass cannot be attributed to human activities. The rarity of gray fox in the underpass was hypothesized to be caused by the presence of coyote, but the activity patterns of predator, coyote, and prey, gray fox, are not strongly correlated. Gray fox rarity is most likely due to its low population density in the area, while lack of deer in the underpass is most likely due to some unexplored characteristics of the underpass or deer behavioral patterns.

Population Densities

When seeking to explain the absence of mule deer and gray fox in the underpass, we sought to understand if deer and fox are truly avoiding the underpass or if they simply have a low probability of being photographed in the underpass due to their low population density. On September 25, 2012, the first and only photograph of a gray fox in the underpass was recorded. Over the 3 year study, no mule deer have been photographed in the underpass.

The results of our density estimates were consistent with our hypothesis that gray fox are rarely photographed in the underpass due to their low density, but mule deer absence in the underpass is not proportional with their density. To contextualize these results, we compared our results to similar peer-reviewed literature.

Researchers studying tiger density with camera traps found that 1,000 trap nights obtained a 95% confidence level for proving species absence (Carbone et al. 2001). This minimum number of trap nights has since been used as a standard of reference in other studies (Kelly and Holub 2008). Our cameras in the underpass were active for 726 days. This may indicate that deer are truly absent from the underpass, but more trap days are needed for a 95% confidence level. However, we estimated that the density of deer at the surrounding cameras is roughly 8.6 times higher than the density of the species that Rowcliffe et al. (2008) used to create the 95% confidence level (deer estimated density: 0.43 individuals/ square kilometer; tiger density used to create confidence level: 0.05 individuals/ square kilometer). Based on these findings, we concluded that the rarity of gray fox in the underpass was due to its exceptionally low population density in the surrounding area. Deer have a density about five times greater than gray fox, but deer have never been photographed in the underpass over the course of the three year study. This finding leads us to believe that population density is unrelated to deer absence from the underpass.

The estimations for density that we obtained seem similar to like studies. For example, a study on coyote density in the Santa Monica Mountains (which is less than 35 miles from our study site) reported a density of 2.4 to 3 individuals per square kilometer in a human-frequented area (Fedriani et al. 2001) compared to our median value of 4.93 individuals per square kilometer. Little data is available on gray fox density. Gray foxes are under-studied because they are not as economically valuable as other fox species (Feldhamer et al. 2003). The most comparable data to ours is island fox density data for the Southern California Channel Islands. Island fox density ranges from 0.3 to 15.9 foxes per square kilometer. This is higher than our gray fox density estimation (median value of 0.131 individuals per square kilometer); however, the authors report that gray fox densities are lower than island fox due to fewer island fox predators. A density study estimated approximately 4 mule deer per km^2 in chaparral habitat of Arizona, and 5.5 to 10.3 mule deer per km^2 in desert shrub (Feldhamer et al. 2003). This density estimation is higher than our calculated density (0.885 individuals per square kilometer), but could be influenced by a multitude of factors such as water sources or species interactions.

Species Accumulation

We found that a greater number of species were photographed by cameras close to the opening of the underpass compared to fewer species photographed in the underpass. These results indicate that the animals are getting close but not going through the underpass. Interestingly, the far cameras were found to have fewer species than the underpass or road cameras, likely due to their isolated location. Camera C4 had recorded seven out of the eight species of interest within less than 200 days of the study. The eighth species was a mountain lion, spotted much later in the study. No other camera reached beyond six out of the eight species. The underpass camera U2 stayed constant at five species recorded until about 500 days into the study, when it finally captured a sixth species, a fox. The underpass camera never captured a deer nor a mountain lion. The close camera reached a high species level very quickly (six species in fewer than 100 days) compared to other cameras which took 550-650 days to record six out of the eight species. From this result we can presume that animals are approaching the underpass but not proceeding through, and tend to frequent pathways more than remote vegetated areas.

Underpass Characteristics

Sound levels less than 60 db, lack of deep water, screening from roads and trails, presence of native habitat on both sides of the underpass, and the presence of a dirt floor were other characteristics associated with wildlife movement through an underpasses (Ventura 2003, Ng et al. 2004). The sound levels in the Los Piñetos underpass were above 60 db and the crossing was not screened from roads or trails frequented by people. However, the underpass is characterized by a lack of deep water, the presence of a dirt floor, and native habitat on either end. The vegetation within and directly surrounding the underpass is sparse. Future research about the importance of these underpass characteristics relative to each other will clarify the effects of these characteristics on mule deer and gray fox.

Potential Alternative Linkages

From the results obtained from camera R1, located at a large fence break, and R2, pointed toward a large metal culvert, it is evident that species may be using alternative methods of transversal to cross the freeway. Coyote, bobcat, and skunk were recorded going through the break in the Caltrans fence. We cannot see where these animals traveled after exiting the fence, but we can assume that they went across the freeway. Although not recorded, it can be hypothesized that all other species can use any of the fence breaks on the west side of the freeway to get onto the freeway. However, there are no large fence breaks on the east side of our study site, leading us to believe that fence breaks are not sufficient means to connect the two isolated habitats. The only large mammal recorded at the metal culvert was a coyote. We can assume that the coyote traveled the length of the culvert to the other side of the freeway. Our study did not record other mammals using this culvert, but it is possible that bobcat, badger, raccoon, or skunk could potentially use this culvert as an alternative crossing point other than the underpass. This culvert is too small for mountain lion and mule deer to use. The Sierra Highway bridges are not a viable wildland linkages because Sierra Highway is a major boulevard heavily frequented by vehicle traffic, the noise level is much louder than Los Piñetos, and there is no natural ground or vegetation in or around the bridges.

Mule Deer Absence

Clevenger and Waltho (2000) determined that the most important characteristics affecting deer's willingness to transverse through underpasses were: noise level, corridor dimensions, and human activity. They also found that deer were somewhat affected by humans, but structural attributes of the underpass were ultimately more important in a deer's choice in using the underpass. The openness ratio of an underpass is defined as (opening width x height)/(length of crossing) (Reed et al. 1975). The Los Piñetos underpass is 51.6 m in length and 25 m in width, and ranges between 6.1–7.6 m in height (Freidin et al. 2011). From these dimensions we calculated the openness ratio to be 3.4 (metric). These dimensions are much larger than the average recommended minimums synthesized from past studies (3.71 m height, 6.61 m width, openness 0.38) (Table 5). The reason mule deer may be unwilling to transverse this underpass is due to factors other than the underpass's dimensions.

Table 5: A synthesis of study recommendations for fencing height, underpass height, width, and openness. The average of these values will serve as the best estimate for the minimum adequate underpass and fence dimensions that deer would be willing to transverse.

	Minimum fencing height (m)	Minimum underpass height (m)	Minimum underpass width (m)	Minimum Openness ratio (metric)
Reed et al. (1975)	2.4	4.27	4.27	0.6
Gordon & Anderson (2003)	2.4	2.4	3.35	0.3
Donaldson (2005)	1.5	3.66	-	0.25
Foster & Humphrey (1995)	2.1	2.1	-	-
Ford (1980)	-	-	12.2	-
Ward (1980)	3	6.1	-	-
Average	2.28	3.71	6.61	0.38

Upon reviewing the literature, we had reason to believe that the presence of humans could be preventing mule deer from using the underpass. When comparing the activity pattern radar graphs of deer and human, it is evident that mule deer are crepuscular and nocturnal, while human activity was diurnal, meaning the two species are active at different times of the day. As demonstrated by the trap rate graphs, we found that deer and humans have no spatial correlation. Deer and humans occupy the same locations, so deer do not seem to be avoiding locations that humans occupy with any significant frequency. Deer have been seen in "C" cameras that lead right up to the underpass, but do not enter (Appendix A7). Based on these results, we believe deer are not avoiding the underpass due to human activity. The data supports that deer may be avoiding the underpass due to its characteristics such as its lack of cover, topography, or sound levels.

Mastro et al. (2008) and Donaldson (2005) suggest that fencing in a funnel shape leading up to the underpass or "V-shaped" topography are the most effective way to coax deer into using it. Vegetation is just as important as corridor dimensions in a deer's decision to pass through an underpass (Bier and Loe 1992). The Los Piñetos underpass has very little vegetation in and around it. This is troublesome for deer because there is nowhere to seek refuge and they are vulnerable to predation. We have also observed that there is neither funnel shaped fencing nor natural topography that would guide deer into the Los Piñetos underpass.

As mentioned in the previous section, the physical presence of people was not positively or negatively correlated with deer movement, but we did not exclude the possibility that other aspects of human activity, such as sound, may affect their use of the underpass. According to Romin and Dalton (1992) mule deer may be afraid of sound levels above ~92 decibels. Evidence indicates that they never habituate to noise (Richens et al. 1978, Reed et al. 1975, Moen et al. 1982). SR-14 has ten lanes and produces significant traffic noise, which may drive deer away from the underpass. All "R" cameras on the west side of the freeway reached a peak sound level of over 92 dB. This may be a reason as to why we never captured any photos of deer on the west side of the freeway. The "U" cameras in the underpass reached up to 88 dB during the short 30 second sample taken (Appendix A6). During peak traffic hours the underpass gets louder and reaches over 92 dB. Mule deer would shy away from this loud area and be isolated to the open space on the east side of the freeway where peak decibel readings stayed below ~85 dB, and average sound readings stayed at ~70 dB or quieter.

Gray Fox Rarity

Upon evaluating the temporal activity radar graphs, we can see that gray fox and coyote have similar temporal activity patterns. We compared the spatial activity patterns of coyote and gray fox to see if intra-guild competition or predation was preventing gray fox from moving through the underpass. As demonstrated by the trap rate graphs, neither a positive nor negative correlation between the spatial activity patterns of coyote and gray fox could be found. Coyote and gray fox were found to be active at similar times during the day at similar locations, however, the small sample size of gray fox prevented a conclusion about the influence of predator-prey relations on gray fox underpass use.

Our estimate of density for gray fox was 0.131 individuals per kilometer squared with a total of 20 photographs captured at all camera stations. The trap rate in the underpass was 0.001 photos per camera day, while the gray fox trap rate at all camera stations was 0.005

photos per camera day. The single picture of a gray fox captured in the underpass is consistent with their low density (Appendix A8).

To further analyze the gray fox low-density hypothesis, we compared gray fox underpass trap rates to those of other key species (Table 6). The above trap rates demonstrate that for most species, the trap rate in the underpass is similar to the overall trap rate at all camera stations. This suggests that the underpass is a funnel for movement for many species. It also suggests that gray fox are not actively avoiding the underpass.

Table 6: Comparison of trap rates in underpass with overall trap rates

Species	Trap rate in underpass (photos/camera days)	Total trap rate (photos/camera days)
Coyote	0.5	0.44
Mule Deer	0	0.04
Gray Fox	0.001	0.005
Badger	0.008	0.003
Bobcat	0.18	0.16

Seasonal Variation

Mule deer are most active in August to November, which is consistent with the deer's mating season (Reed et al. 1974, Vogel 1989, Donaldson 2005). Gray fox are most active in the winter months which is consistent with the beginning of fox mating season (Layne 1958, Vu 2009). Coyote, bobcat, mule deer, and gray fox are all most active in the fall and winter months, and not as prevalent in the spring and summer months. These species of interest are temporally similar. If further studies were to be done, months that would get the most results are September through January. Experiments should be timed accordingly to capture this peak in wildlife activity.

Directionality Study

We determined that there is no clear directional pattern of species going neither east nor west through the underpass (Figure A5). These, gene pools of animals using the underpass do not seem to be isolated by the obstruction of SR-14.

Error and Sensitivity of Results

One of the components of data analysis that was most sensitive to error is the density estimation derived by Rowcliffe et al. (2008). This is because this estimation requires an estimate of species' daily range of movement, and unfortunately there are no studies on daily movement that perfectly represent our species and habitat-type. However, even with a range of values to account for this uncertainty, coyote consistently has a higher population density estimate, followed by deer and then fox. Once again, this supports that deer are truly absent from the underpass.

Potential Missed Captures in the Underpass

Between September 27, 2011 and February 8, 2013, there was only one camera in the underpass. The underpass is 25 m across and the cameras have a radius of capture of 20 m. The camera was installed ~2 m from the wall, and there is a 3 m zone on the opposite side of the underpass where no animals could be detected because it is out of the range of the camera. It is possible that animals could have crossed through the underpass without being detected by our cameras.

V. Conclusions

The detailed examination of species' underpass use affords conclusions not only about our study site, but wildlife connectivity in general. With respect to our study site, the infrequent underpass use by gray fox is most likely due to their low population density in the surrounding area, as supported by the estimated 0.131 km^{-2} population density. Both gray fox and coyote have underpass trap rates appearing consistent with their calculated densities. Similar data comparisons for mule deer show no relationship between density and underpass use, because there were no deer photographed using the underpass.

Mule deer absence in the underpass is not linked to low population density or human influence. The calculated population density 0.885 km^{-2} is contrasted by lack of underpass use. Other aspects about the underpass, perhaps the design, lack of vegetation, guide-ways, or the surrounding noise level, may be the reason why mule deer are not using the underpass. Literature suggests that the design of this particular underpass should encourage mule deer use; however, not a single mule deer has been recorded using the underpass in the past three years. In addition, to better define the activity of mule deer local, to Santa Clarita, this finding is important for those involved in developing connectivity strategies for wildlife in other areas, as it encourages a possible revamping of underpass criteria for mule deer. The absence of mule deer in the underpass despite a moderate deer population density further enforces the need for an in-depth behavioral study of mule deer in similar environments. If further research were to be done here, or at any related site, tests should be conducted between the months of September to January to take advantage of the peak wildlife activity. Video recordings should be made directly outside an underpass to record and understand the behavior of mule deer as they encounter the entrance of the underpass. Vegetation cover or other shelter should be placed in an around a similar barren underpass to test the importance of cover in deer's decision to transverse through an underpass.

Despite the lack of use by mule deer, the Los Piñetos underpass has shown to be a vital connectivity point for numerous species, placing importance for environmental review of any future development in the area. Among these species is the mountain lion, as well as a California Species of Special Concern, the American badger (Appendix A9). Future development in the area may negatively influence the species that are slow to adapt to human influence. Development may also impede access to the adjacent Gate King Open space habitat within the Newhall Wedge.

Our results show evident temporal niche partitioning by humans and animals. Wildlife activity peaks at night when human activity is at its minimum level. Said partitioning may be enforced by the heightened proportion of human activity in the area (Figure 4). Thousands of pictures of humans were recorded, with a large proportion due to vehicle presence. The combination of moderate development in the area with high vehicular and recreational disturbance may contribute to wildlife activity occurring primarily in the night.

Our research is important because it: 1) can be used to assess the environmental impacts of development in the area, 2) demonstrates a need to redefine underpass criteria for mule deer, 3) reveals new knowledge of the natural history of mammals in the area, including rare species and species of special concern, 4) establishes results and suggestions to aid in the development of other connectivity strategies for wildlife, particularly with respect to the willingness of coyotes to use underpasses and 5) affirms the fact that Los Piñetos is indeed an important corridor for wildlife movement in the area.

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Appendix

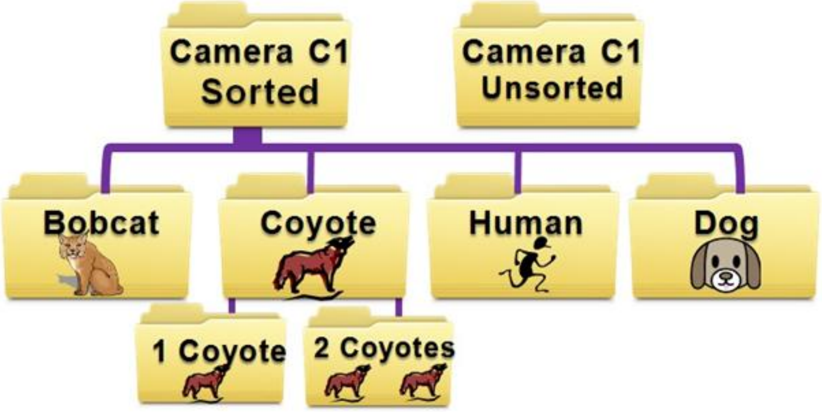

Figure A1: A simplified schematic of sorting conventions.

Camera	Alias	Category	Camera Type	Description
F1	Big Rock	Far	Cuddeback	Along Refinery Grapevine. 125 m from main trail. In the entrance of a small topographic valley.
F2	Earthquake	Far	Cuddeback/Ltl Acorn	Along Elsmere Canyon Rd. 45 m from main hiking trail. Small sandy trail leading up to camera. Heavy shrubbery.
F3	Very Far	Far	Cuddeback	Along Elsmere Canyon Rd. 20 m from main hiking trail. Heavy shrubbery.
C1	Face Underpass	Close	Cuddeback	East of underpass. <1 m off Los Piñetos Rd. Soft sandy soil, near vegetation. Along MRCA/Caltrans property line, facing dirt road leading into underpass.
C2	Face Away	Close	Cuddeback	East of Underpass. <1 m off of Los Piñetos Rd. Soft sandy soil, near natural vegetation, along MRCA /Caltrans property line. Facing dirt road leading into underpass.
C3	Yellow Gate	Close	Cuddeback	East of Underpass. <1 m off of side asphalt road, rocky terrain, medium grade slope, facing diagonally down slope. Near natural vegetation, grasses, located next to barbed wire fence and metal yellow gate.
C4	Road Bend	Close	Cuddeback/Ltl Acorn	East of underpass. Located off off Los Piñetos Rd. approx. 1 m. Thick soil, near lots of natural vegetation. At cross roads between intersection of gully (with barbed wire fence), side asphalt road, and Los Piñetos Rd. (asphalt), slightly rocky terrain. Behind camera is gradual slope
U1	Parking Lot	Underpass	Cuddeback	West of underpass. At intersection of Los Piñetos Rd. and Remsen St.

U2	Freeway West	Underpass	Cuddeback/Ltl Acorn	In underpass on west side of Hwy 14. Approx 1 m from compared dirt road. Very visible along road.
U3	Old East	Underpass	Cuddeback	In underpass on east side of Hwy 14. Dense sandy terrain approx. 15 m from compacted dirt road.
U4	Freeway East	Underpass	Ltl Acorn	In underpass on east side of Hwy 14. Dense sandy terrain approx. 20 m from compacted dirt road.
R1	Fence Break	Remsen	Ltl Acorn	West of Underpass. Approx 20 m from road. Very grassy. Facing entrance to large fence break along Remsen St.
R2	Culvert	Remsen	Ltl Acorn	West of Underpass. 10 m from Remsen St. Installed on a fence on the Cal trans/Santa Clarita border. Facing concrete wash pathway and metal culvert (1m diameter) going through the 14 Hwy.
R3	Gas Line	Remsen	Ltl Acorn	West of Underpass . <1m off of the road. Along Remsen St facing the road. Within a coast live oak/riparian microhabitat. Leading up to a small intermittent stream.

Camera	**Distance from Underpass (m)**	**Distance from Freeway Median (m)**	**Active Trap Nights**	**Sensitivity Setting**	**Photo Interval (sec)**	**Number of Photos per trigger**	**Facing**
F1	730	168	763	High	60	1	SE
F2	1000	290	753	Low	10	2	NW
F3	1800	330	66	High	60	1	NE
C1	60	33	393	High	60	1	N
C2	62	60	100	High	60	1	N
C3	200	150	100	High	60	1	SE
C4	250	155	644	Low	30	2	SE
U1	75	50	40	High	60	1	NW
U2	0	19	571	Normal	1	2	NW
U3	0	9	40	High	60	1	SE
U4	0	23	73	Normal	1	2	SE
R1	330	47	75	Low	45	1	S
R2	480	53	31	Low	10	2	NE
R3	230	71	35	Normal	5	1	W

Camera	GPS Location	Installed	Uninstalled	Notes
F1	N 34.34887, W 118.50213	04/09/11	05/11/13	
F2	N 34.35439, W 118.50231	04/09/11	05/11/13	Switched from Cuddeback camera to Ltl Acorn 02/18/13
F3	N 34.35708, W 118.50233	04/09/11	06/13/11	
C1	N 34.35065, W 118.50396	03/06/11	04/01/12	Found Vandalized 04/01/12
C2	N 34.35058, W 118.50378	03/06/11	06/13/11	
C3	N 34.35108, W 118.50275	03/06/11	06/13/11	
C4	N 34.3508, W 118.5026	03/06/11	05/11/13	Cuddeback found Vandalized 04/01/12. Reset as an Ltl Acorn 09/01/12
U1	N 34.35055, W 118.50478	05/05/11	09/27/11	Stolen between 09/03/2011 - 10/27/2011
U2	N 34.35023, W 118.50444	05/05/11	05/11/13	Cuddeback found Vandalized 04/01/12. Reset as an Ltl Acorn 07/16/12. Malfunction 8/3/12-09/01/12. Found stolen sometime between 4/7/2013 and 4/29/13
U3	N 34.35311, W 118.50411	05/05/11	06/13/11	
U4	N 34.35061, W 118.50408	02/18/13	05/11/13	
R1	N 34.35297, W 118.50568	02/09/13	05/11/13	
R2	N 34.35429, W 118.50616	02/18/13	05/11/13	
R3	N 34.35193, W 118.50560	04/07/13	05/11/13	

Figure A2: Complete data set for all cameras used in the study.

Figure A3: Photos of 2013 camera installation in the field. (A) Pounding metal post into the ground for camera R1. (B) Group is scouting out an ideal camera location around an area with a metal culvert. (C) Group is bolting U4 camera onto a metal post. (D) Group is uninstalling Camera C4. (E) Group is examining coyote tracks left on dirt. (F) 12-megapixel infrared LTL Acorn Scouting Camera. (G) Group is bolting camera R3 onto a metal post. (H) Camera R1, fully installed with metal security box and padlock.

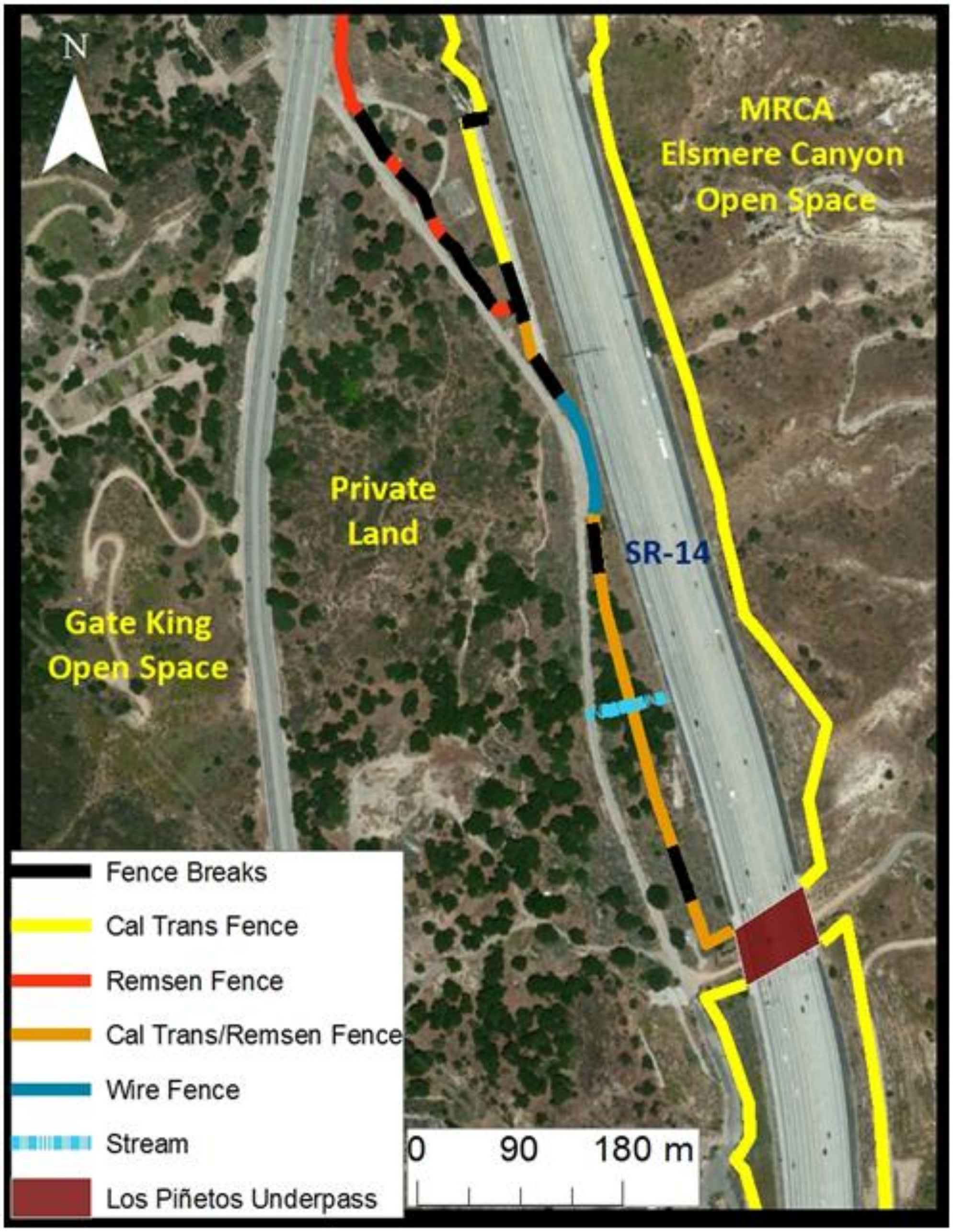

Figure A4: An aerial map depicting fences and fence breaks in the area around the Los Piñetos underpass.

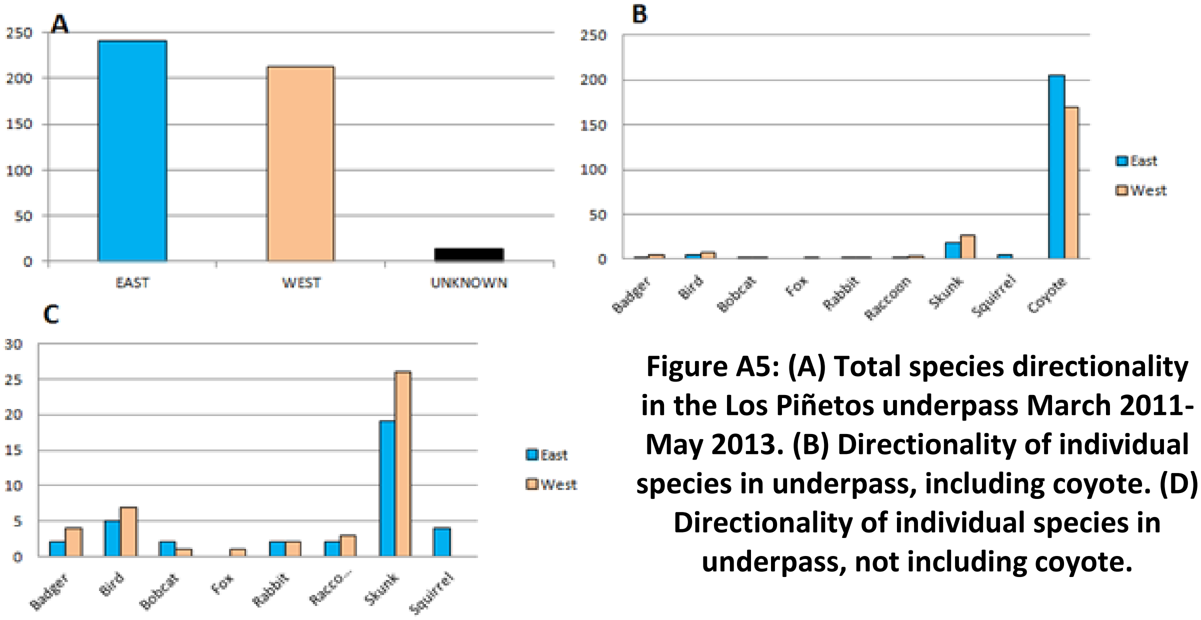

Figure A5: (A) Total species directionality in the Los Piñetos underpass March 2011-May 2013. (B) Directionality of individual species in underpass, including coyote. (D) Directionality of individual species in underpass, not including coyote.

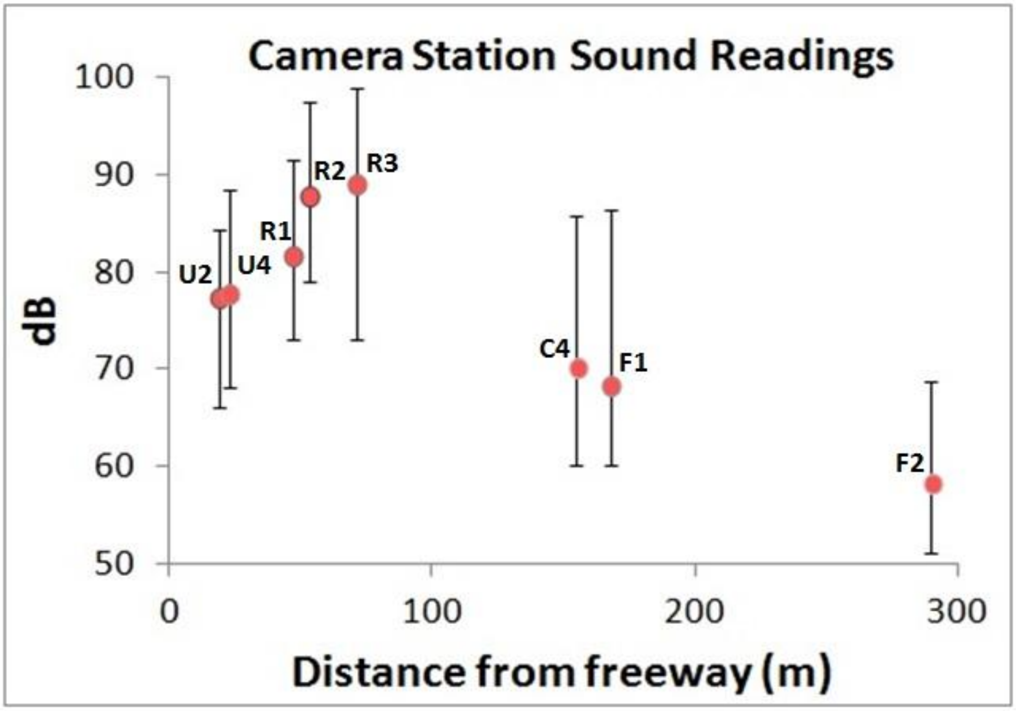

Figure A6: Average sound readings (dB) at each camera station as a function of distance from the freeway. Error bars show maximum and minimum sound levels recorded in the sample. Sound samples recorded May 11, 2013 between 11:00 am to 1:00pm.

Figure A7: Despite plenty of mule deer sightings near the underpass at "C" cameras, shown in this photo, not one was captured to be using the underpass as a crossing path.

Figure A8: The lone evidence of gray fox's usage of the Los Piñetos underpass.

Figure A9: American badger shown to be using the Los Piñetos underpass as a corridor.

Figure A10: (A) Gray fox at camera F1. (B) Gray fox at camera C4. (C) Gray fox at camera F2. (D) Three mule deer at camera F1. (E) Juvenile mule deer photographed during daylight at camera F1. (F) Male mule deer at camera F1. (G) Bobcat photographed during daylight at camera F2. (H) Bobcat kitten at camera F1. (I) Bobcat with prey in its mouth in the underpass at camera U2. (J) Three coyote at camera C4. (K) Alert coyote at camera C4. (L) Coyote captured at dusk at camera C4. (M) Skunk at camera F1. (N) Two raccoons at camera C4. (O) Mountain lion at camera F2.