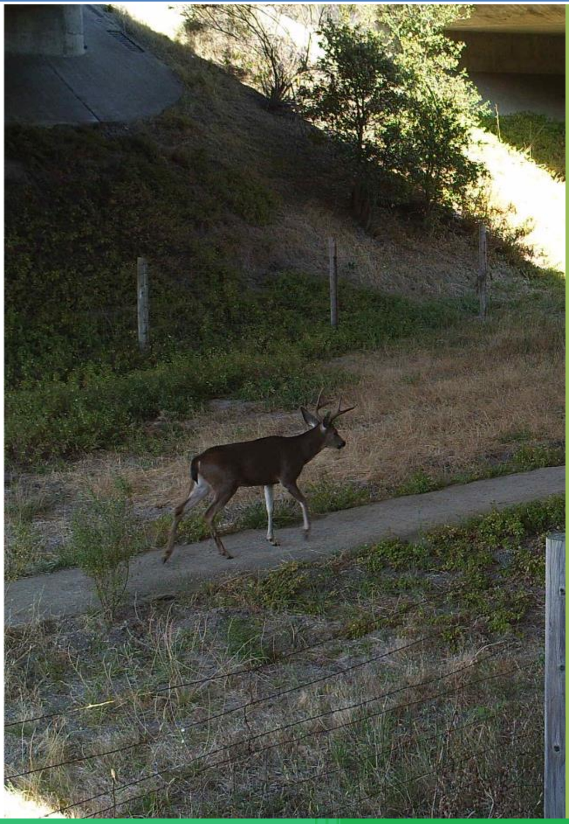
Interstate 280 Wildlife Connectivity Research Study: Findings and Recommendations



The UC Davis Road Ecology Center
In Collaboration with Caltrans, District 4 and the California Department of Fish and Wildlife

Interstate 280 Wildlife Connectivity Research Study: Findings and Recommendations

UC Davis Road Ecology Center
Caltrans, District 4
California Department of Fish & Wildlife

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About the author Dr. Shilling (fmshilling@ucdavis.edu) is a research scientist at the University of California, Davis who studies how environmental sciences intersect with environmental policy. He is the Co-Director of the Road Ecology Center, which is the only center of its kind in the US studying road system effects on natural systems and people.

Cover photo: Mule deer crossing safely under I-280 at Edgewood County Park; Tanya Diamond

EXECUTIVE SUMMARY

Many California interstates provide commuter traffic and goods movement among regions and cities through wild, protected areas. Collisions between wildlife and vehicles occur frequently, which has prompted Caltrans to seek assistance in assessing the nature, extent, and solutions to potential conflict between traffic and animals. Wildlife-vehicle collisions can pose a risk to human drivers and wildlife populations and species. Interstate 280 (I-280) has seen fatal and non-fatal (to people) collisions between cars and animals. Because of concern about the rate of collisions along this interstate, Caltrans and the Transportation Enhancement Program of the USDOT saw fit to fund a study of the causes of collisions and possible solutions. The objectives of the study were to understand how wildlife were currently using available under-crossing structures, how wildlife in general and mule deer (Odocoileus hemionus) in particular interact with the highway and adjacent habitat, and to develop mitigation for risk reduction. This report describes analysis of wildlife-vehicle conflicts and wildlife movement in association with I-280, as well as scenarios for mitigation of impacts to wildlife and people from collisions.

Three types of wildlife observation data along I-280 were used to characterize wildlife movement: wildlife-vehicle collisions (WVC), images from wildlife camera traps at highway under-crossings, opportunistic track surveys, and deer movement patterns using GPS-collars.

WVC occurrences were from Caltrans' monitoring of carcass retrieval and disposal by Maintenance crews and opportunistic observations of carcasses by participants in the California Roadkill Observation System (http://wildlifecrossing.net/california). We identified statistically-significant WVC hotspots and calculated rates of collisions with any animal and with deer in particular. There are various costs associated with a collision between a deer and a vehicle. On average, a collision with a deer costs $6,671 (Hujser et al., 2009). We found that the cost of deer collisions on I-280 each year, between 2005 and 2012, varied from <$1,000 to >$40,000 per mile (Figure 1). To put this number in perspective, it can cost ~$20,000/mile to augment a 5-6 foot chain link fence to make it an 8-foot fence and up to $100,000/mile to construct a new 8-foot fence. There were segments of high costs from deer collisions

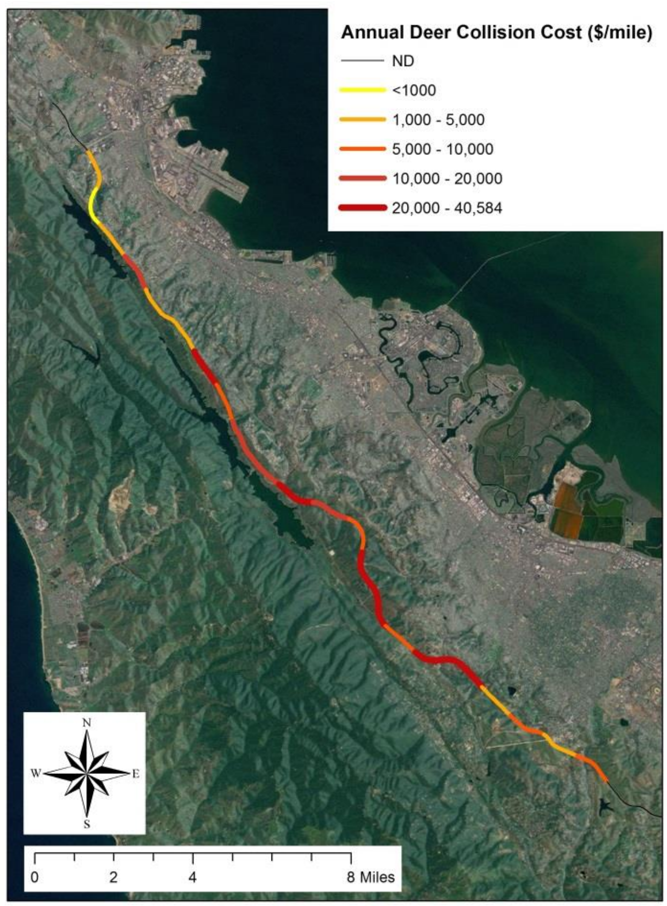

Figure 12. Estimated costs of deer-vehicle-collisions per mile.

(>$5,000) throughout the study area. Certain stretches would pay for themselves in terms of avoided costs from deer collisions in a matter of 3-5 years.

We tracked twenty four female deer using GPS collars (Lotek, Inc.) between December, 2011 and January, 2013. Collared deer often approached and moved back and forth near the interstate and two were hit by vehicles. Only 5 of the 24 collared deer passed back and forth under the highway, all using the same 2 crossing structures, a large vegetated underpass and a minor road under-crossing.

Beginning in October, 2011, camera traps captured still and video images at 9 street underpasses, 1 bicycle over-crossing, 6 culverts, and 6 wildlife trails adjacent to crossing structures. We measured species diversity and the relationship between wildlife passage and human use of structures. There was a strong negative relationship between the presence of humans hiking, driving, walking dogs, or riding bikes and the use of existing crossing structures by wildlife. In addition, there was very low species diversity observed using crossings at either interstate. Only 9 native mammal species were observed to use crossing structures, which was not a function of camera sensitivity as they could detect movement of small lizards. During 16 fairly continuous months of photo-monitoring of crossing structures, we detected 1,341 mule deer passing safely under the right-of-way. Because of the rate of traffic on the surface of interstate, it is likely that most deer attempting to cross would be struck. Passing 1,341 deer in 16 months allowed a cost avoidance of 1,341 deer times $6,671/collision = $8.9 million, or $6.7 million/year. This could be considered one value of the structures.

Mitigating WVC consists of where to act and what actions to take to reduce risk to drivers and animals. Managing conflict between vehicles and wildlife along I-280 requires identifying priority areas, fencing to keep deer and other animals from accessing the road surface, construction of new underpasses or enhancement of existing structures, and re-management of existing underpasses to reduce human use. Future research should focus on responses of wildlife to reduced human passage at underpasses, the different management required in developed vs. undeveloped areas, and methods to increase species diversity at crossing structures.

PROJECT PURPOSE

There are two purposes of this project. First and foremost is to increase the safety of the commuters who choose to drive this Highway by assessment of the wildlife-vehicle collision problem & then ascertaining how to most efficiently reduce the impacts of wildlife-vehicle-collisions, benefiting both wildlife and public. The second purpose of equal importance is to restore the wildlife movement and habitat connectivity across I-280. The lessons learned, data collected and solutions chosen to restore the wildlife movement and habitat connectivity with ththis project will be available to guide future projects of similar purpose in California, including along I-280 itself.

The section of I-280 that runs through San Mateo County sees many auto collisions on an annual basis due to deer-crossings alone (Figure 1). Human injury can result when vehicles collide with the deer and other large animals. The mitigation solutions recommended here should result in reduction of wildlife-vehicle collisions. This reduction is as important to the safety of the commuters as it is to wildlife movement.

There are a handful of strategies used across America aimed at counteracting road-kill and habitat fragmentation. They range from site-specific projects such as underpasses, vegetated overpasses or the widening of box culverts, to regional models that combine landscape ecology, conservation biology and human safety concerns with long-range transportation planning.

The Santa Clara > News

Daniel Strickland Mourned on Campus

Engineering Professor, 27, dies in car accident

By Kurt Wagner

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Updated: Thursday, September 29, 2011 11:09

One of Kerry Strickland's favorite motherly duties was sending her son, Daniel, McDonald's gift cards throughout his collegiate career, first while he was at Seattle University, then later during his graduate schooling at Stanford. She wanted to make sure that her son was always eating.

And like any concerned mother, the gift card would always be followed up by a phone call a week or so later just to check in on her only child — and always, she got the same response: yes mom, I bought a meal or two, but then I found someone on the street who needed the card a lot more than I did and I gave it to them.

That was the way Daniel Strickland lived life.

"He was always giving something to somebody else, whether it was his heart, his knowledge, his ear for listening," said Kerry. "The most that I want people to remember about my son was not only the academics, but the heart that he had and the person that he was is what made me the proudest."

Courtesy of Kelly Strickland
Daniel Strickland died last week when his car was rear ended on I-280.

Daniel Strickland, an associate professor of Engineering at Santa Clara, died last Friday due to extensive brain damage suffered in an auto accident the night before on I-280 S. Daniel hit a deer on the road, stalling his car in the lane and was rear ended moments later by another vehicle. He died less than 24 hours later at Stanford Hospital. He was 27 years old.

Daniel came to Santa Clara in the fall of 2010, just a few months removed from Stanford University where he graduated with a Master's degree and a Ph.D. In his short time at Santa Clara, Daniel was a favorite among students because of his ability to relate to them in ways that were deeper than just academics, said senior Mike Sizemore, one of Daniel's research assistants, who described him as just "one of the guys."

Anders Rodin

Figure 1 Motorist killed on I-280 after collision with a deer.

INTRODUCTION

Interstates carry heavy traffic loads, often through wildlife habitat. The combination of heavy traffic and wildlife movement results in wildlife-vehicle collisions (WVC), the rate of which can often be reduced through structural amendments to the highways. High-speed collisions with deer, and attempts to avoid collisions with any animal, pose serious risks to drivers and animals. In addition, reduced movement of animals through an ecosystem because of aversion to highways, or mortality on the road surface, will reduce genetic flows within and among populations of individual species. There were two purposes of this project: 1) To assess potential causes and locations of deer-vehicle collisions; 2) To ascertain how to most efficiently increase permeability to wildlife of interstates, thus significantly reducing the impacts of wildlife-vehicle-collisions, benefiting both wildlife and public.

Besides providing structural and foraging values, a critical function of ecosystems and habitats is providing connectivity for wildlife movement. Connectivity provides opportunities to move among areas required for various life cycle functions. Roads, highways, and land uses can pose barriers of varying permeability to wildlife species. Permeability refers to the effectiveness of an area or structure to provide access and movement. Interstates passing through natural habitats of the West may restrict movement of ground-dwelling vertebrates because of the lack of sufficient crossing structures, WVCs on the road surface, and aversion to the light, noise, and movement of traffic. Understanding the relative permeability of interstates and segments of highways, increases the likelihood that responsible Departments of Transportation (DOTs) can act quickly to improve permeability and reduce risks to animals at the individual to population scale.

Driver safety can be compromised in two significant ways by animal entry onto a highway's surface. One is collision with larger animals, which can damage the vehicle and potentially lead to driver injury or death. Another is through attempts by drivers to avoid collision with an animal of any size, which can result in the driver crashing, potentially injuring themselves, or others. By examining rates of accidents among highway segments and among highways, DOTs can prioritize areas for action to reduce risk of collisions.

As with many other DOTs, California Department of Transportation (Caltrans) collects two important kinds of data useful for prioritizing actions to reduce WVC: traffic collision reports (from California Highway Patrol) and carcass clean-up reports (from Caltrans Division of Maintenance staff). The vast majority of these reports involve the results of collision with mule deer (Odocoileus hemionus) which are numerous across much of the state and large enough to cause vehicular damage and driver-injury. These kinds of data are important for the investigation of problem stretches of highway, potential effects on ungulate populations, and decision-support for actions to reduce WVC (Green et al., 2011) and to understand effectiveness of mitigation actions (Craighead et al., 2011). Since 2009, California has been host to the California Roadkill Observation System (http://wildlifcrossing.net/california), one of 3 state-scale, online reporting systems (the others are in ME and ID). Opportunistic and targeted (to road segments) collection of roadkill/WVC observations can be used along with collision and carcass clean-up reports to develop a full picture of where WVC are occurring, which species are involved, and what times of day and year may have higher rates of collision.

Wildlife-vehicle collisions represent the unsuccessful crossing of a roadway by an animal. In order to understand and improve successful crossing, it is also important to measure passage of animals through crossing structures and adjacent to the roadway. Free-standing cameras, triggered by movement of animals (wildlife cameras) are often used to sample or census animal movement through constrained structures under or over roadways. Radio- or GPS-collars are often used to track hourly or daily movement of individual animals throughout their home range or dispersal/migratory travel. Deer use of certain habitat types near urban highways may contribute to their being involved in collisions with vehicles (Found and Boyce, 2011), allowing predictive models to be developed that could be used in assisting analysis and planning. Understanding wildlife movement in association with highways, highway infrastructure, and WVC are critical to placing effective mitigation structures and actions (Barnum et al., 2003 a,b; Barnum et al., 2007).

The section of interest on I-280 runs parallel with Crystal Springs Reservoir. There have been many collisions between deer and cars along this stretch of highway, resulting in injury, property damage, and impacts to deer populations. We speculate that the deer may be crossing the freeway to get to water.

There are several investigation and planning activities associated with this project. One is investigating where the highway poses the most significant movement barrier to mammals, especially deer. Because daily, seasonal, and dispersal movement may be important to many species in the area, a significant barrier could pose a threat to species' persistence in the region, including isolating certain populations on either side of the corridor. Planning and building mitigation and enhancing activities to reduce wildlife-vehicle conflict will be the second phase of the project.

We used WVC occurrences, wildlife camera pictures, and GPS-collars to estimate successful and unsuccessful crossing of two study interstates in California (I-280 and I-80) and hourly movement of deer alongside one interstate (I-280). Analyses of successful and unsuccessful movement were used to spatially determine where conflict was severe and potential mitigations best targeted. We also estimated species diversity at the highway and potential impacts of the highway on animal behavior. We provide corresponding recommendations for Caltrans to retrofit both highways to improve permeability and reduce rates of traffic accidents.

STUDY AREA

This interstate is a commuting highway between South San Francisco Bay cities (such as San Jose) and the city of San Francisco. It also serves immediately abutting cities along the San Francisco Peninsula. Approximately 22 miles of the I-280 transportation corridor (the study section) is adjacent to varying quality wildlife habitat (e.g., oak woodland, grassland) and has sufficient traffic volume (>200,000 vehicles/day; Caltrans, 2010) to pose a significant barrier to wildlife movement and result in significant wildlife-traffic conflict. In effect, this corridor bisects the range of a resident deer herd, significantly impacting the herd and public safety.

EXISTING INFRASTRUCTURE

Using Caltrans data, we found 20 bridge spans in the study section, which included structures like the highway 92 interchange, which had 3 spans. We also found 68 culverts, which were primarily small

(<36”) drainage structures, but also included several large (>8’ x 8’) box culverts for use by people (Figure 2).

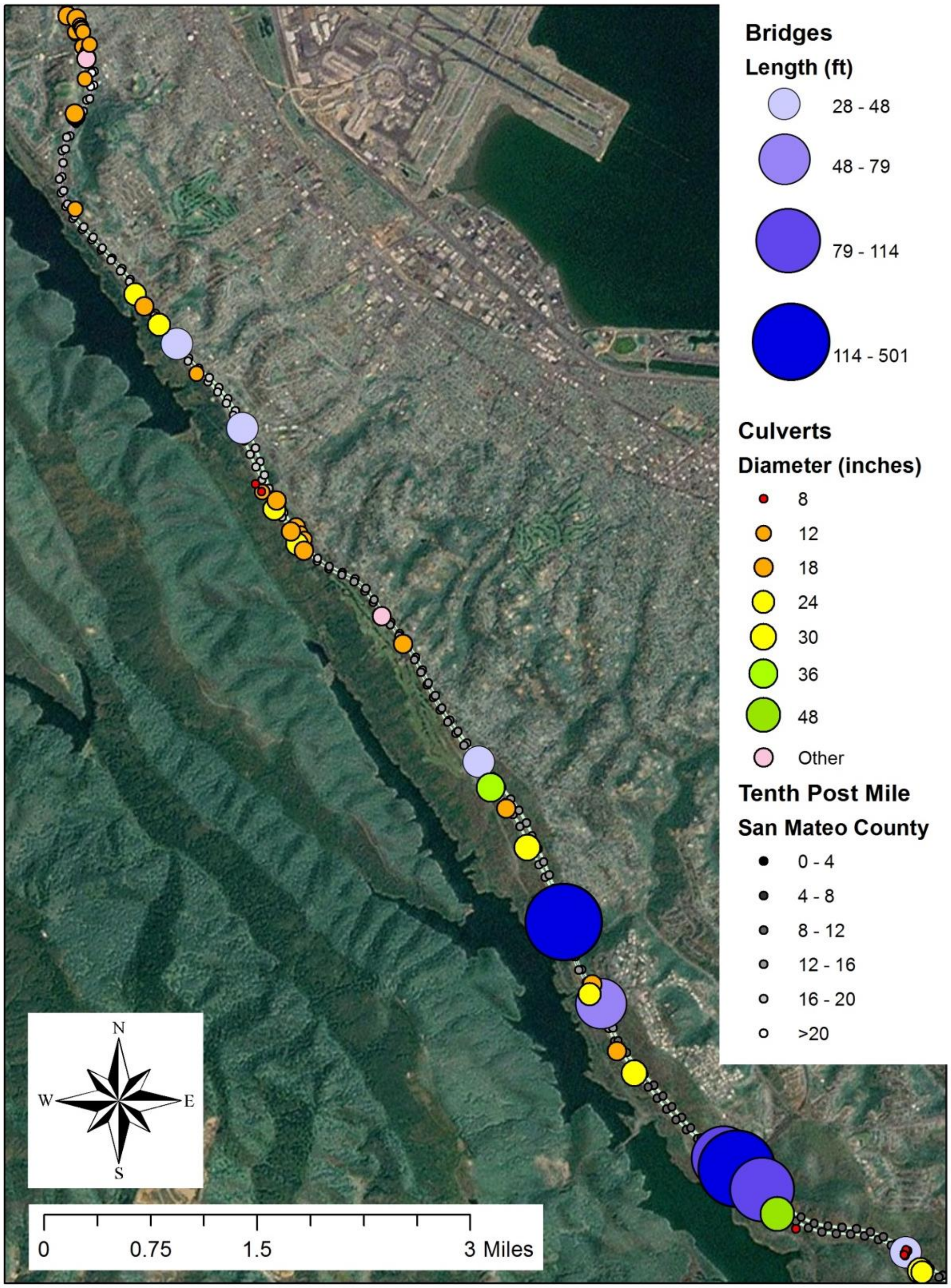


Figure 2A. **Infrastructure elements (culverts, bridges, and post-miles) along I-280, north section.**

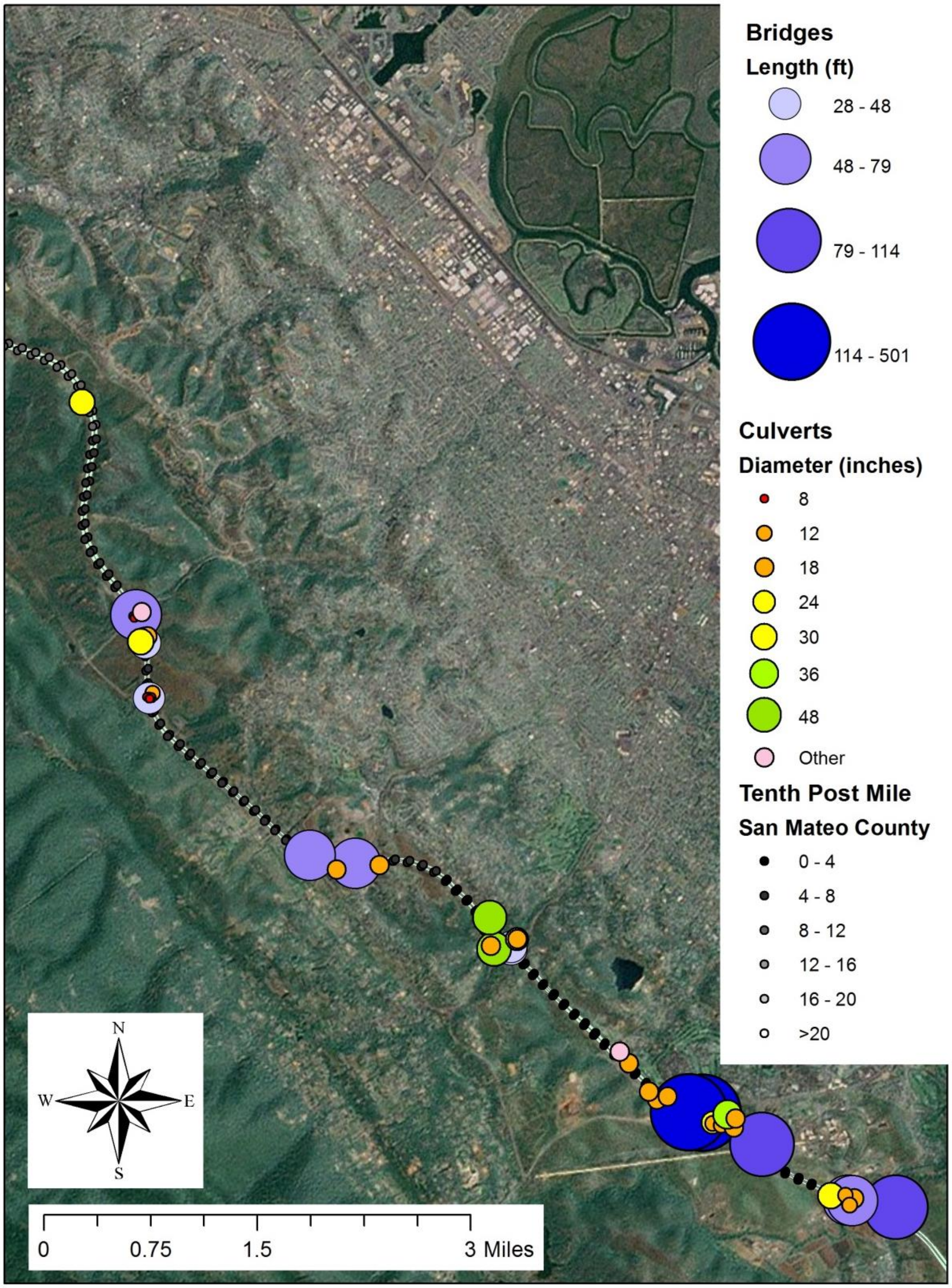


Figure 2B. Infrastructure elements (culverts, bridges, and post-miles) along I-280, south section.

The land-cover alongside I-280 is very different on either side of the interstate (Figure 3). On one side are the extensive residential neighborhoods of the Eastern Peninsula. On the other side are intact habitats of various types, in a mixture of private and public ownership.

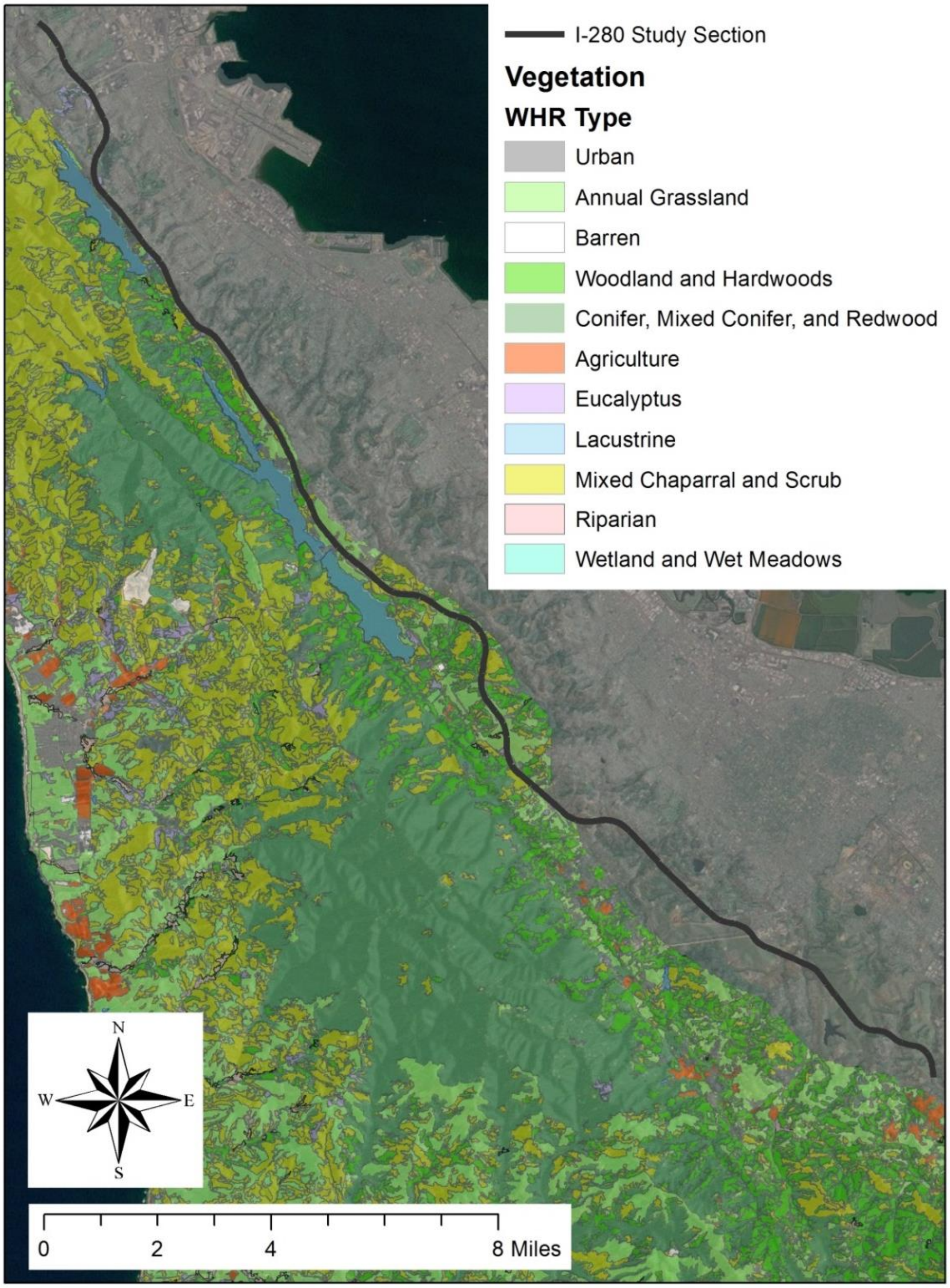


Figure 3. Vegetation/land-cover in the vicinity of the I-280 study section.

APPROACH: DATA COLLECTION

To study how deer and other wildlife species were moving near and across I-280, three methods were used in concert: 1) GPS-collaring of deer near the right-of-way (ROW), 2) recording roadkills in GIS from Caltrans databases and volunteer observations, and 3) recording animal movements through over and under-crossings across the I-280 ROW. The approach is to combine the data outputs and results from these methods into a coherent understanding of where, when, and what kinds of risks occur along the interstate and what mitigation measures would reduce the risk.

DEER MOVEMENT

Twenty-four mule deer were collared for 6 months with a GPS device that hourly reported the location of the deer, whether it was alive or not, and ambient climatic conditions. Deer were immobilized and collars affixed by trained California Department of Fish and Game (now Fish and Wildlife) staff (Figure 4). Lotek Globalstar GPS collars were used, with timed 6-month magnetic drop-off devices. In the first round of collaring, 15 deer were collared, but one collar discontinued reporting its position after ~4 months. In the second round, only 10 deer were collared due to limitations on finding deer in a timely manner. GPS data were used to analyze the frequency of different kinds of habitat use by deer, proximity of deer to the ROW, and frequency of contacting or crossing the ROW.

Figure 4. California Department of Fish and Wildlife biologists and newspaper reporter with a deer that has just been collared and is recovering.

Figure 5A. Box culvert at Sandhill Road

Cameras and were placed at potential opportunistic crossing locations under and over I-280 in order to understand actual wildlife movement in response to the highway. Remote, motion-triggered wildlife cameras (Bushnell Trophy Cam II) were used to measure the wildlife and human use of crossing structures and the seasonal and daily use of structures. We deployed 40 cameras and experienced >50% camera loss during the study period, despite using security devices. The data from the cameras were used to estimate the rates of human and wildlife use of structure-location. Cameras were deployed at 24 positions at 18 locations along the interstate for 18 months (11/2011 to 4/2013) with a range of sampling per location of 25 to 366 days. A location refers to a single structure (e.g., Figure 5A), where a position refers to where a camera was attached and pointed at part of the structure (e.g., opening of a culvert, Figure 5B). Cameras were checked weekly to monthly. Approximately one camera was stolen per month, resulting in missing stretches of data. Street crossings with many cars and pedestrians were sampled for 1-7 days to provide approximate rates of use, while limiting the chance of camera theft.

Figure 5B. Road Ecology Center staff at round culvert at Sandhill Road

The “exif” data (e.g., date, time, camera model, etc.) were extracted from each photograph. Animals in each photograph or video were analyzed for species identity, movement behavior, gender, and age-class. All photographs were uploaded into a customized web application (“Cam-WON”) for the storage, management, querying, and display of large wildlife-picture databases (http://wildlifeobserver.net/I280). Cam-WON provides a service to operators of wildlife cameras to manage their camera network in a web-based environment enabling sharing of photos and data from their projects. Users can register a project, upload individual or bulk photo-observations, display the locations of cameras, and display a catalog of pictures in the database. The operating system is Ubuntu Server 12.04 LTS (Precise Pangolin) running PHP version 5.3, Apache 2, MySQL 5, Drupal 7, and ancillary programs. Because all photographs are entered with their attributes (e.g., time, date, location, animal id), these attributes can be used as the basis for queries from the system’s relational database.

We also collected track records at locations that were particularly difficult to place wildlife cameras because of theft. Tracks were recorded at 3 locations (Farm Hill Road, Canada road, and Vista Point Road) on 8 dates between October, 2011 and May, 2012. Soft substrate (dirt or sand) was surveyed for tracks on both sides of the roadway and in the media, if present. Tracks were identified and recorded using photographed.

WILDLIFE-VEHICLE COLLISIONS

Three main kinds of wildlife-vehicle collision data on I-280 have been collected: a) Caltrans maintenance records of carcass retrieval and disposal, b) Caltrans/CHP records of collisions involving injury or property damage, and c) WVC observations from project staff and volunteer observers driving this stretch of highway; data from the California Roadkill Observation System (http://wildlifecrossing.net/california). Carcass occurrence data were used to understand the frequency of collisions per highway segment and per species, as well as to identify "hotspots" – statistically-significant concentrations of carcasses.

APPROACH: DATA ANALYSES

Three types of data analyses were performed: 1) rates, locations, and types of wildlife-vehicle collisions; 2) rates, species, and impediments to successful wildlife movement across (under) the right-of-way; and 3) movement and occupancy of deer in relation to the right-of-way and to habitat types adjacent to the highway.

WILDLIFE-VEHICLE COLLISIONS

To identify areas where mitigation might be effective in reducing WVC, we used two methods of estimating WVC intensity for highway segments. One method was the count of WVC per unit length (e.g., per mile), which allows comparison of WVC against some threshold of concern (Wang et al., 2010). Hotspots of some event of interest are often measured by estimating the spatial autocorrelation of the events. We used a measure of spatial autocorrelation test called Getis-Ord, which results in a measure of statistical significance of the correlation, the "GiZ" score. The method compares the density of an event (i.e., number of carcasses per highway segment) for each set of neighboring analysis units. If there are big differences between a highway segment and its neighbors, a significant result will be found. If similarly low or high densities of an event are found among segments, then there may be a finding of no significance (and thus no hotspot). The GiZ score can be calculated for different lengths of highway segment, which can affect where hotspots are identified. Shorter segment lengths (e.g., 1/10th of a mile) may result in more hotspots than longer segments (e.g., 1 mile) because there is greater likelihood at shorter distances that there will be a difference between # carcasses averaged over segments than at greater distances. We also used estimates of the total cost of deer-vehicle collisions to provide estimates of the cost per mile segment per year from deer-vehicle collisions (Hujser et al., 2009). This provides another way to prioritize areas for mitigation, including both spatial location and economic benefits from mitigation action.

SUCCESSFUL WILDLIFE MOVEMENT

To identify the relative permeability of existing crossing structures (i.e., culverts, under- and over-crossings), wildlife and human use of structures was measured. Animals in each photograph from the cameras were identified by the authors and the rate of wildlife and human use of structures calculated. Duplicate photographs were removed from the dataset before further analyses. Events were defined as appearance of an animal (or person) in the picture, where repeated appearances by the same animal within 10 minutes were counted as one event. Multiple individuals of the same species in 10 minutes were counted as separate events. Animal use of 3 structures was also assessed through recording of tracks in soft substrate. Tracks were measured, photographed, and recorded on 8 eight occasions between 10/2011 and 5/2012 and reported as species occurrence.

MOVEMENT AND LOCATIONS OF DEER

To understand deer use of habitat adjacent to I-280 and aversion to the highway, deer were tracked using GPS-collars. Data were manually downloaded from GPS collars recovered after 6 months of being on the deer. The hourly GPS locations were converted to shapefiles. To understand possible habitat selection patterns by deer, hourly locations were compared to vegetation types from the California Vegetation map (CALVEG) developed by the USDA Forest Service Region 5 and collaborating state agencies (http://www.fs.usda.gov/main/r5/landmanagement/gis). Hourly locations were also compared with distance from the highway right-of-way (assumed to begin 20 m from the center-line). The vegetation and distance association for each location was calculated using the "isectpntpoly" and "isectpntrast" tools, respectively, of the Geospatial Modeling Environment toolset (http://www.spatialecology.com/gme/). To measure habitat selection for individual deer and all collared deer in the study, deer location distributions among habitat types was compared with the availability (Manly, 2002) of those types within 1 km of the highway was carried out using the Chi-Square test (chisq.test) in R (http://www.r-project.org/). The null hypothesis for the test was that deer randomly use habitat at the rate at which it is available to them in the study area (Boyce et al., 2002).

EXISTING FENCE INFRASTRUCTURE

There is fencing along most of the length of the I280 study section. The height, fence segment lengths, distance from ROW, and condition of the fence segments were surveyed and recorded. Field data sheets were completed by field staff. Heights were measured using tape measures; intermediate lengths and distances were measured using a laser range finder; locations were determined using a GPS device. About 1/3 of the ROW was not accessible for surveying due to topography, dense vegetation, private property ownership, lack of access point, or staff concerns about safety in the field. The data in field forms were transcribed into an Excel spreadsheet and a KML file in Google Earth for visualization.

RESULTS

The results are organized into 3 main sections: wildlife-vehicle collisions, successful wildlife movement across I-280, and deer movement.

WILDLIFE-VEHICLE COLLISIONS

Two methods were used to identify hotspots (locations of concern) of wildlife-vehicle collision (WVC) along each of the study interstates: Number of carcasses collected by Caltrans Maintenance staff or recorded by California Roadkill Observation System (CROS) observers; and locations of spatially-clustered WVC. Each type of data tells a different story and together can help identify and prioritize sites of mitigation action.

Roadkill carcasses were observed at many locations along I-280 south and north bound between Millbrae Rd. and Woodside Rd. (Figure 6). These observations were for 19 species and 381 individual animals.

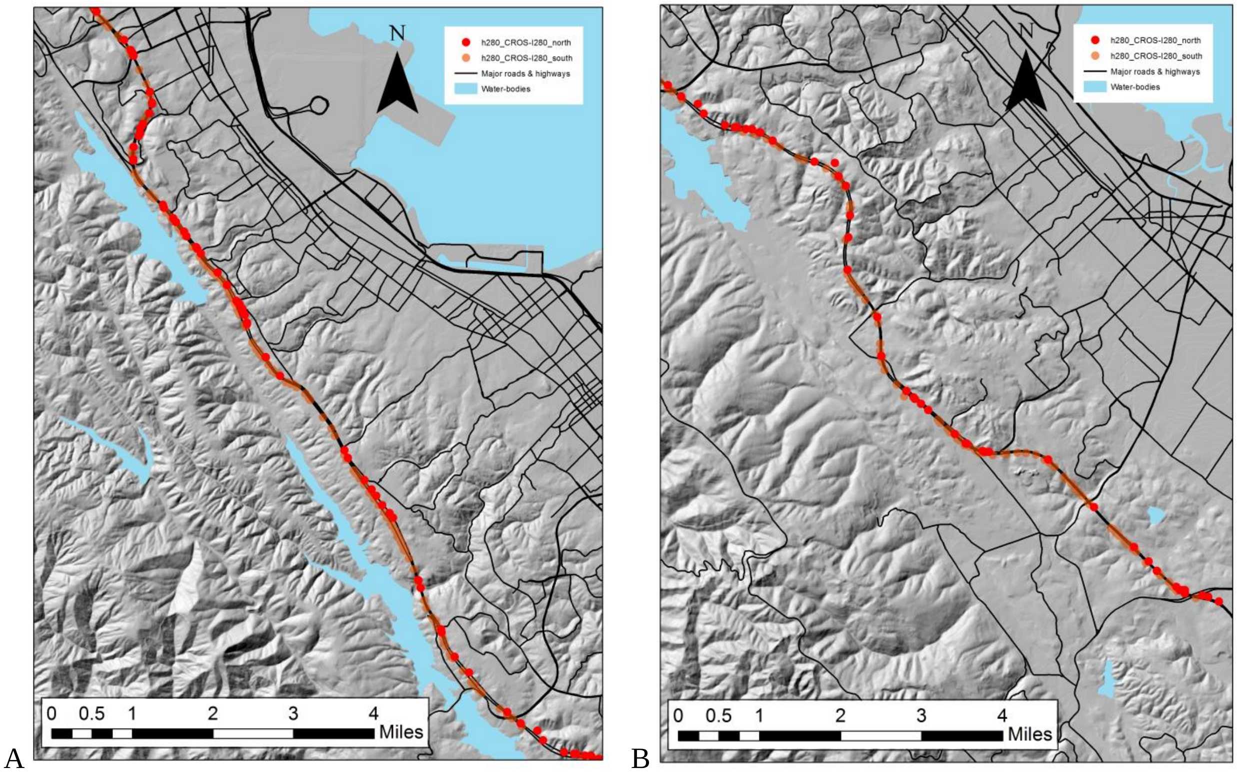


Figure 6. Locations of animal carcasses reported in the California Roadkill Observation System 2009 – 2012, (A) north section and (B) south section.

Many of the observations were for mule deer (46 of 381 carcasses). This species is of particular concern from a collision point of view because property damage, injury, and even death can result when automobiles collide with them. These observations of deer occur at many areas along I-280 (Figure 7).

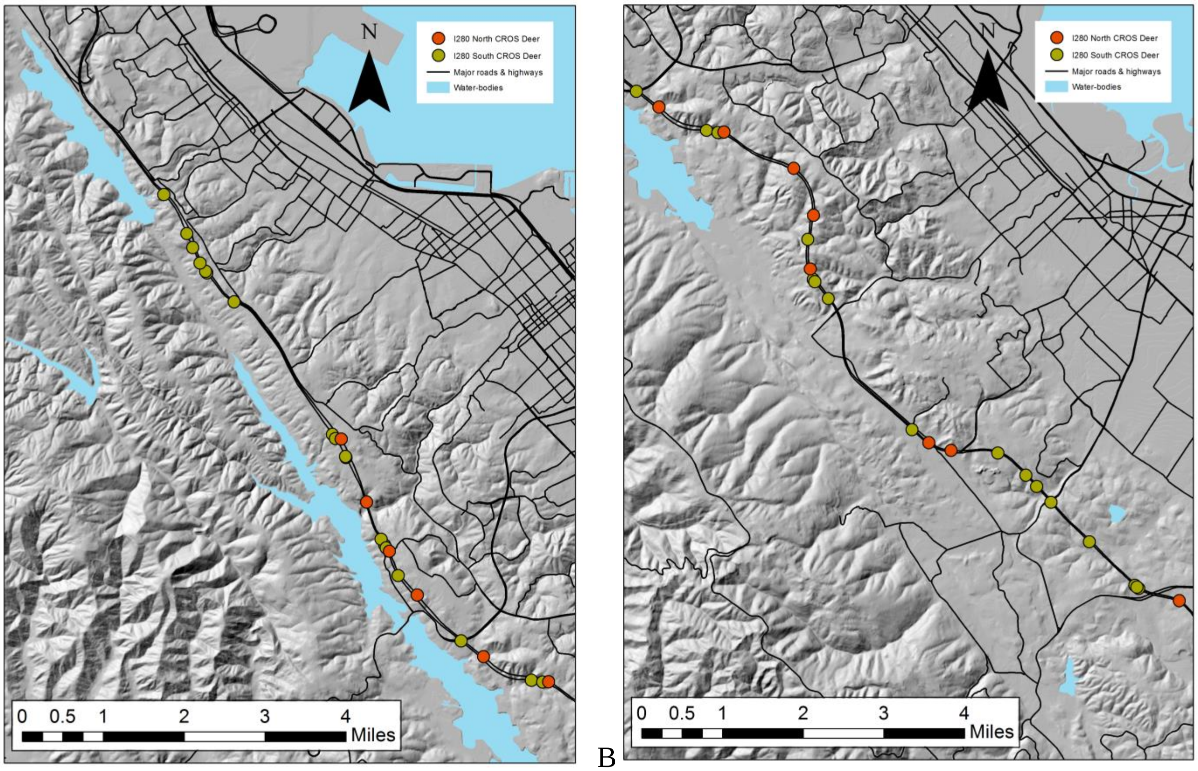


Figure 7. Locations of deer carcasses from the California Roadkill Observation System 2009-2012, (A) north section and (B) south section.

Hotspots of some event of interest are often measured by estimating the spatial autocorrelation of the events. We used a measure of spatial autocorrelation called Getis-Ord, which results in a measure of statistical significance of the correlation, the "GiZ" score. The method compares the density of an event (i.e., number of carcasses per highway segment) for each set of neighboring analysis units. If there are big differences between a highway segment and its neighbors, a significant result will be found. If similarly low or high densities of an event are found among segments, then there will be a finding of no significance (and thus no hotspot). The GiZ score can be calculated for different lengths of highway segment, which can affect where hotspots are identified (figure 3). Shorter segment lengths (e.g., 1/20th of a mile) may result in more hotspots than longer segments (e.g., 1 mile) because there is greater likelihood at shorter distances that there will be a difference between # carcasses averaged over segments than at greater distances.

Three statistically significant hotspots were identified for collisions involving any animal: the longest between Hillcrest Blvd. and 1 mile south of Trousdale Dr. (Figure 8A), a short one at the intersection with Bunker Hill Dr. (Figure 3A), and a third covering ½ mile north of the Farm Hill Blvd. intersection (Figure 8B). The significance of these hotspots is that they are places different from their neighbors, not that non-hotspots lack significance in terms of collisions. Hotspots determined using the CROS data were compared with a summary by Caltrans of deer carcasses per 1/10 point mile and deer carcasses reported in CROS (Figure 9). In every case where Caltrans' data indicates a higher density of deer collisions, there are also records of deer carcasses in CROS and in some cases also a hotspot identified.

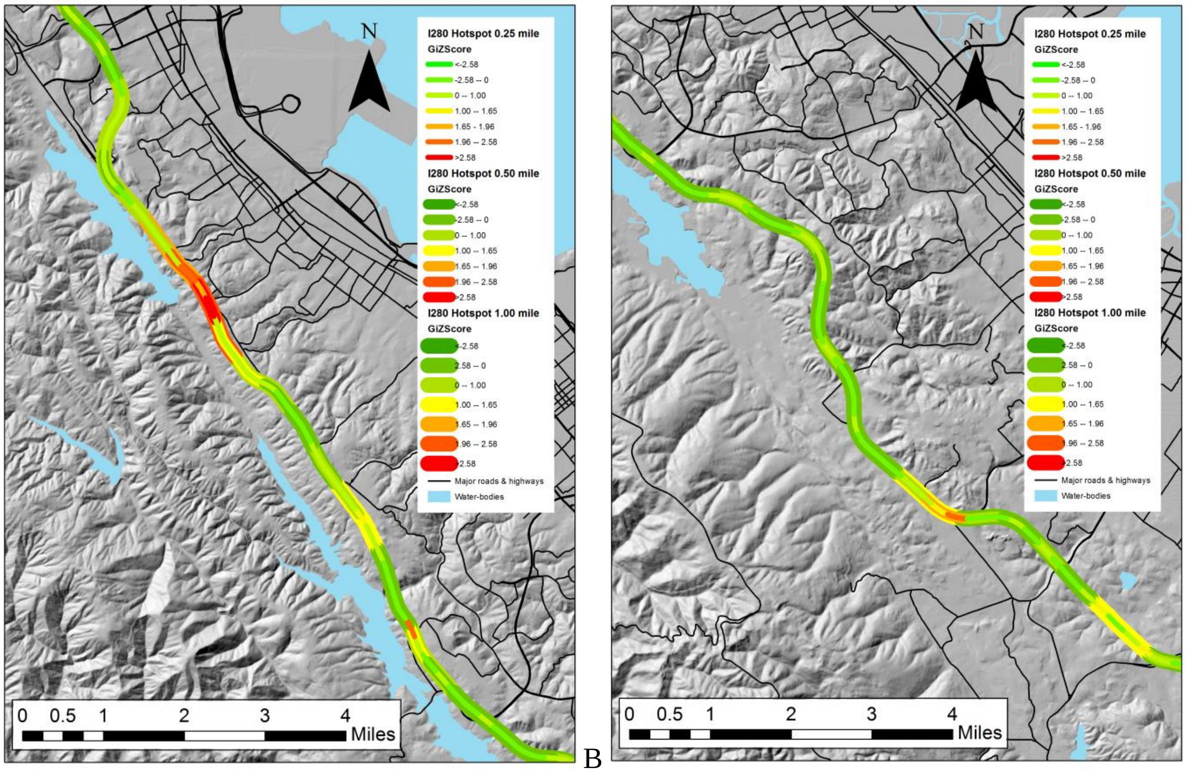
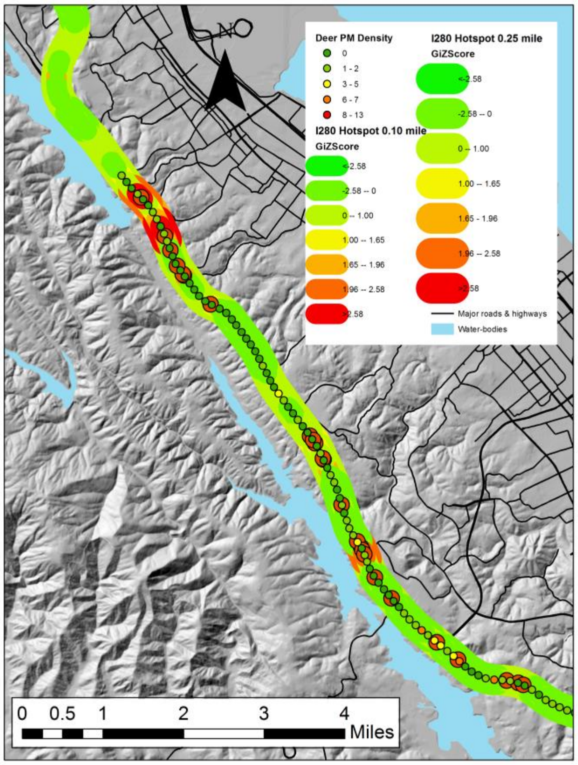


Figure 8. **Hotspot analysis for 0.25, 0.5, and 1 mile segments of I-280. GiZ scores above 1.96 are significant at p<0.05. The scores for shorter segments lie on top of those for longer segments, (A) north section and (B) south section.**



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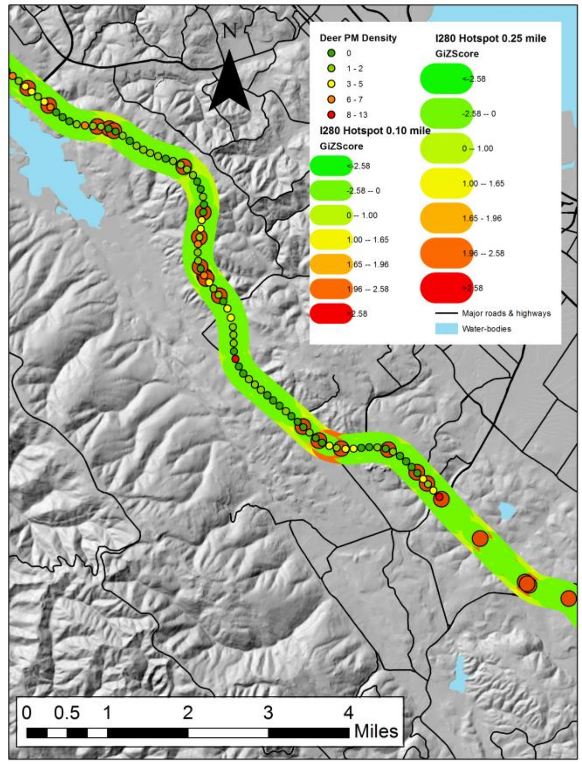
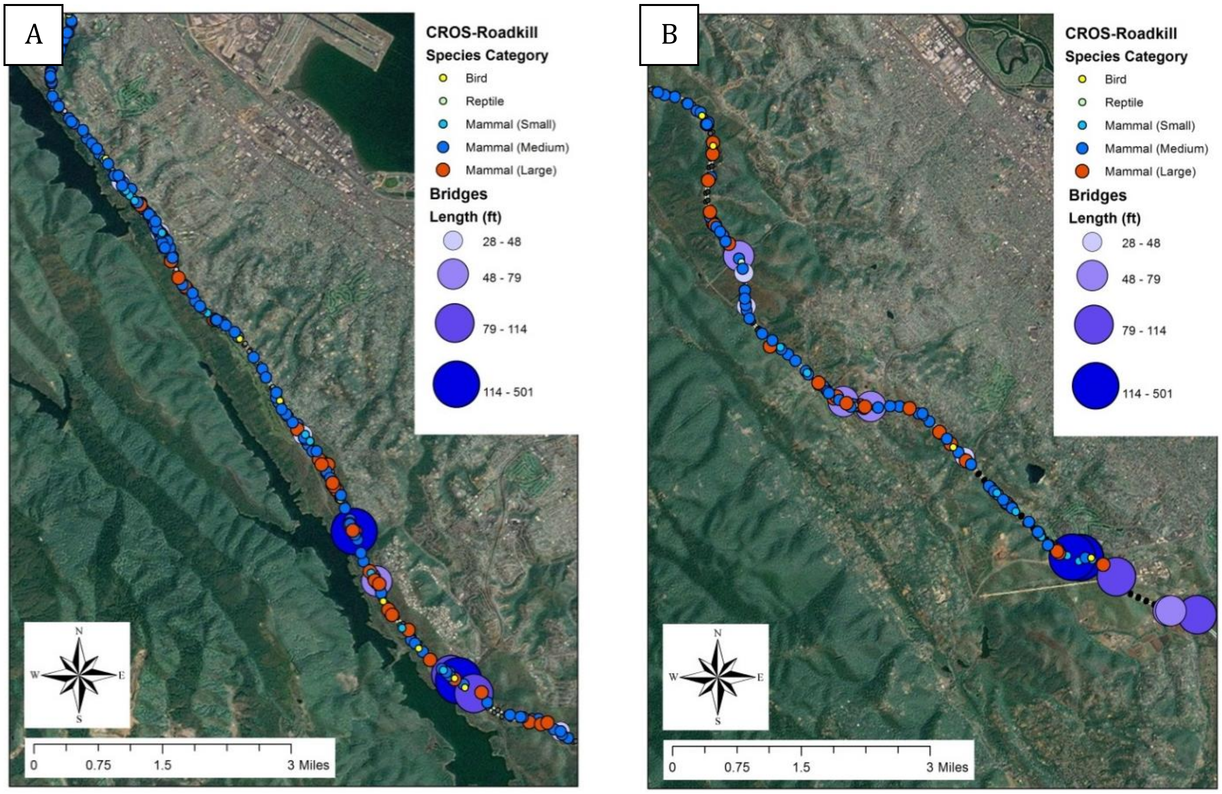


B

Figure 9. Locations of WVC hotspots based on deer carcass counts by post-mile ("Deer PM Density") and spatial clustering of all WVC (0.1 and 0.25 mile segments). The WVC carcass data were for 3 years (2009-2012) from the California Roadkill Observation System. The deer carcass data were for 4 years (2005-2009) from Caltrans. The GiZ score refers to the Getis-Ord statistic of significance, where values >1.96 indicate significant spatial clustering, (A) north section and (B) south section.

The presence of WVC were visually compared to the presence of crossing structures for safe movement across the right-of-way (Figure 10). There was no apparent negative relationship between the presence of WVC and available crossing structures (Figure 10A,B). Deer-vehicle collisions (DVC) are a special sub-set of WVC because of the risk posed to drivers and vehicles from the collision. DVC (data from Caltrans) by post-mile were compared to the availability of crossing structures under or over I-280. There was no apparent relationship between a structure being available and rate of DVC (Figure 10C and 11).



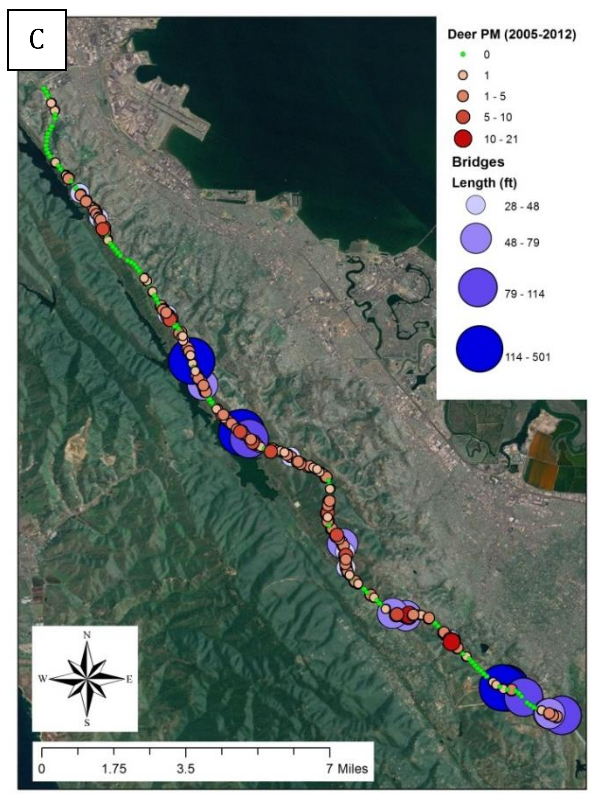


Figure 10. WVC carcass data from the California Roadkill Observation System (2009-12) and availability of bridges of different span length, (A) north section and (B) south section. C) DVC carcasses by post-mile (PM) and availability of bridge structures of different span lengths.

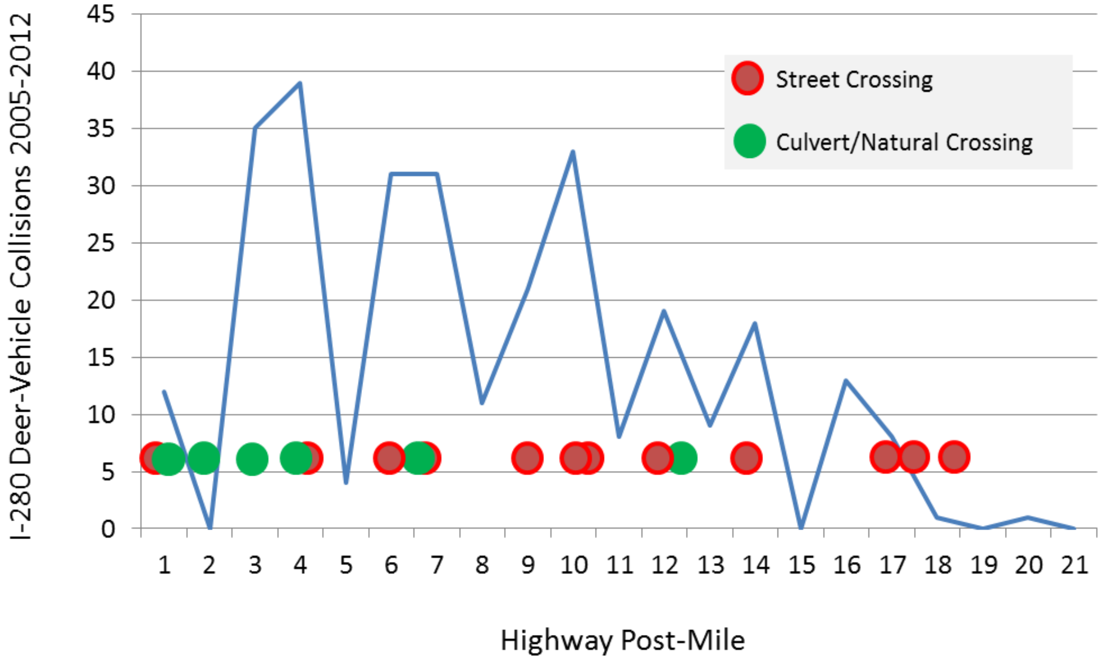


Figure 11. **Comparison of number of deer-vehicle collisions (DVC) on I-280 per post-mile and the approximate location of street, culvert, and natural-bottomed crossing structures.**

There are various costs associated with a collision between a deer and a vehicle. On average, a collision with a deer costs $6,671 (Hujser et al., 2009). The cost of deer collisions each year, between 2005 and 2012, varied from <$1,000 to >$40,000 per mile (Figure 12). To put this number in perspective, it can cost ~$20,000/mile to augment a 5-6 foot chain link fence to make it an 8-foot fence and up to $100,000/mile to construct a new 8-foot fence. There were segments of high costs from deer collisions (>$5,000) throughout the study area. Certain stretches would pay for themselves in terms of avoided costs from deer collisions in a matter of 3-5 years.

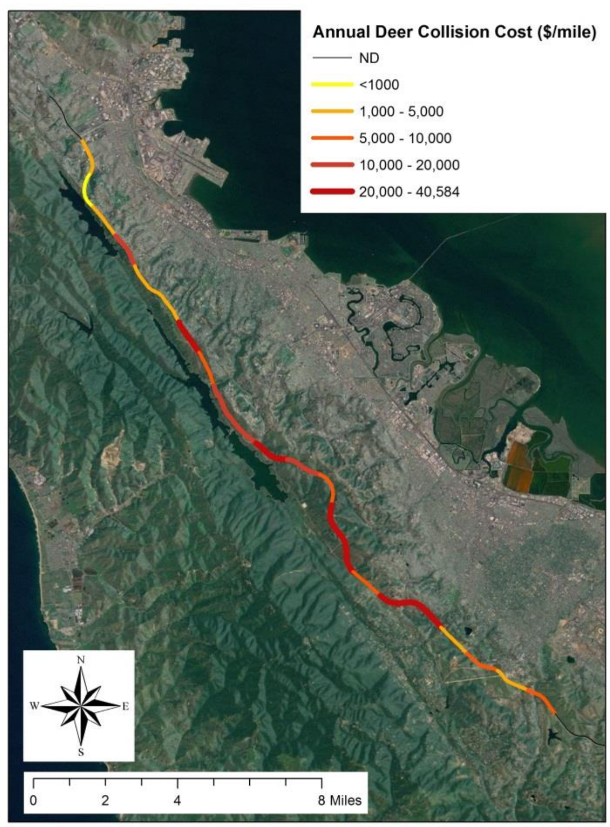


Figure 12. **Estimated costs of deer-vehicle-collisions per mile.**

Both potential and actual wildlife movement were assessed for most of the larger structures crossing I-280. These included street under and over-crossings and large culverts. Street under-crossings provided excellent potential permeability for large (and smaller) mammals (Table 1). Although large culverts were present, their length made them unlikely to support crossing by medium to larger-sized mammals (Table 1), but they could potentially allow crossing by small mammals (and herpetofauna).

Table 1. Characteristics of each major crossing structure and rate of cameras stolen per structure.

Crossing structure name	Length from one side of I280 to the other (m)	Width (across culvert floor,road or trail) (m)	Height (m)	Openness ratio*	Visibility through structure	Ground conditions through structure	Material of structure	# Cameras stolen
Hillcrest Blvd Underpass	46.9	13.7	4.65	1.36	High	Concrete	Concrete	
Trousdale Road Underpass	81.4	19.5	4.65	1.11	High	Concrete	Concrete	
Hayne Road Underpass	75	15.5	4.65	0.96	High	Concrete	Concrete	
Crystal Springs Road Underpass	45.1	12.8	50	14.19	High	Concrete	Concrete	2
Bunker Hill Drive Overpass	122	12.2	ND	ND	High	Concrete	Concrete	1
Highway 92 Interchange	276	12.2	ND	ND	High	Concrete	Concrete	
Ralston Avenue Bike Trail OC	100	2.74	ND	ND	High	Concrete	Concrete	
Vista Point Road Underpass	29.9	13.1	4.65	2.04	High	Concrete	Concrete	4
Edgewood Road Underpass	55	39	4.65	3.30	High			
Edgewood Trail Underpass	51.2	14.6	4.65	1.33	High	Dirt Trail	Concrete	
Canada Underpass	61	12.8	4.65	0.98	High	Concrete	Concrete	4
Farm Hill Road Underpass	91.4	23.5	4.65	1.20	High	Concrete	Concrete	4
Ansel Lane Underpass	81.1	49.7	4.65	2.85	High	Dirt Trail	Concrete	2
Alpine Road Underpass A	113	51.8	4.65	2.13	High	Dirt Trail	Concrete	
Alpine Road Underpass B	18.9	8.5	4.65	2.09	High	Dirt Trail	Concrete	
Hwy 92 Interchange South Culvert	270	1.52	1.48	0.01	Low	Dirt & Rocks	Metal Pipe	
Farm Hill Road Culvert	120	1.22	1.22	0.01	Low	Metal Pipe	Concrete	
Woodside Box Culvert	61	3.05	2.62	0.13	High	Dirt	Concrete	
Sandhill Road Box Culvert	69.5	3.09	3.09	0.14	High	Dirt	Concrete	3
Sandhill Road Round Culvert	160	2.23	2.23	0.03	Low	Concrete	Metal Pipe	2
Alpine Road Round Culvert	245	1.57	1.57	0.01	Low	Concrete	Metal Pipe	
Hwy 92 Interchange South Wildlife Trail						Dirt Trail		
Farm Hill Road Wildlife Trail						Dirt Trail		
Woodside Wildlife Trail						Dirt Trail		
Alpine Road Wildlife Trail						Dirt Trail		
Hwy 92 West Wildlife Trail						Dirt Trail		
Ansel Lane Underpass Game Trail								

* -- The openness ratio is calculated as the height times the width, divided by the length of the structure

Appropriate for large mammals

Appropriate for medium-sized mammals

Appropriate for small mammals

Structure not monitored with wildlife cameras

Dimension estimated using ArcGIS and/or Google Maps

Wildlife cameras

Animals were identified in pictures from cameras at under-crossings, culverts, and on animal trails near the interstate. 1,678 animals were monitored through crossing structures over the entire period (2/2012 to

5/2013; Table 2). The number of animals detected ranged from 0.07 to 2 per day of camera deployment. The highest values were for a trail near the Stanford University Preserve adjacent to I-280. The lowest rates were for a 10-foot box culvert.. Because the size of structures did not seem to explain the rates of animal use, we compared the rates of animal use and human use at each structure. There was a strong negative relationship between rate of human use and rate of animal use (Figure 7). Three structures across I-280 (two street and one bike over-crossing) that were primarily for human walking and vehicular use were not included, but did not provide animal crossing use.

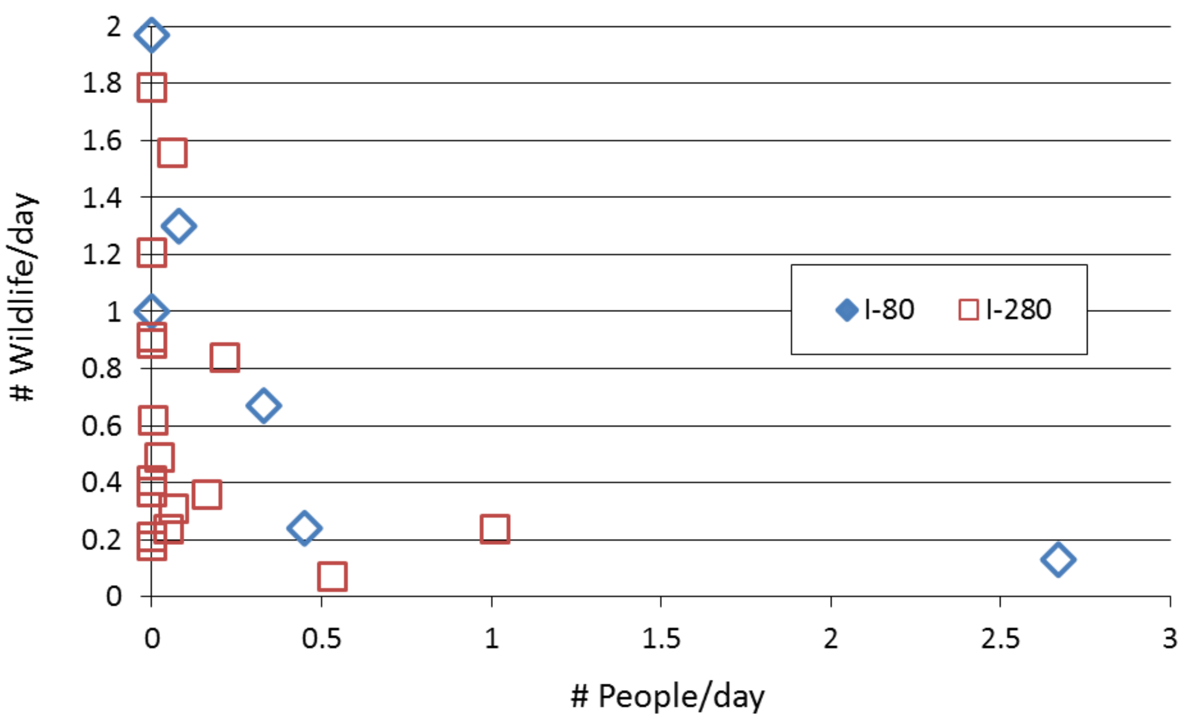


Figure 13. Comparison of wildlife rate of structure use with human use of the same structures. Each symbol represents a different structure. Data from a similar study on I-80 were included in order to increase the power of the analysis and understand the generality of the findings.

Table 2. Summary of wildlife species movement through crossing structures.

Animal	Animal Write-in	Photo Count	Individuals
Mule (or Black tailed) Deer		1025	1341
Raccoon		154	232
Coyote		44	46
Virginia Opossum		28	28
Animal Write-in	Unknown	13	13
Bobcat		10	10
Striped Skunk		3	3
Gray Fox		2	2
Animal Write-in	Squirrel	2	2
Animal Write-in	Rabbit	1	1
Totals		1282	1678

Not all crossing structures were monitored for the entire study period. During 16 fairly continuous months of photo-monitoring of crossing structures, 1,341 mule deer passed safely under the right-of-way (Table 2). Because of the rate of traffic on the surface of interstate, it is likely that most deer attempting to cross would be struck. Passing 1,341 deer in 16 months allowed a cost avoidance of 1,341 deer times $6,671/collision = $8.9 million, or $6.7 million/year. This could be considered one value of the structures.

The number of individual wildlife varied widely among the crossing structures from 0 to 0.9 animals/day. Alpine Ln had the highest rate of animal movement (0.9) and also had the highest species diversity (7 species). Species diversity at most of the crossing structures was very low, ranging from 1 to 3 species (figure). The Alpine Ln crossing is vegetated and includes a creek (http://wildlifeobserver.net/location/alpine-underpass).

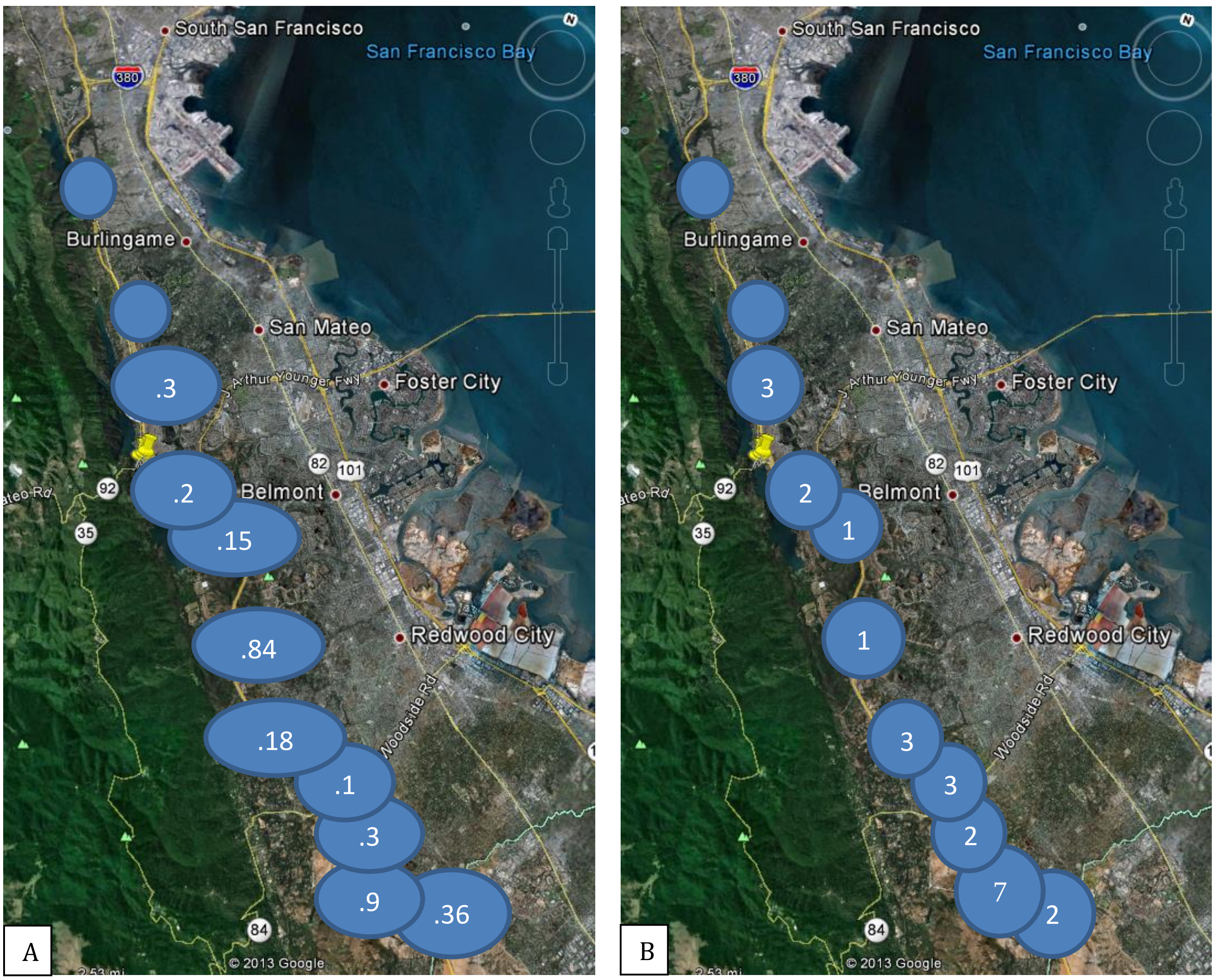


Figure 13. A) Variation in wildlife crossing rate (animals/day) among structures. B) Variation in species diversity among structures (# species).

Animal Tracks

At certain locations, it was not feasible to place cameras, or cameras that were placed were stolen before data could be retrieved. At these locations, animals tracks were recorded, when observed. Because it was usually not possible to tell how many individuals had passed through a structure over a given time period, only the presence or absence of a certain species was recorded (Table 3).

Table 3. Species tracked at each of 3 crossing structures (underpasses).

Location	Side of Underpass	Species	Dates	Direction of Travel
Canada Road Underpass	South side only	Deer and Coyote	10,12/2011; 3,5/2012	East & West
Vista Point Road Underpass	North side only	Coyote	10,11/2011	West
Farm Hill Road Underpass	North, South, and Media	Bobcat and Deer	3,4,5/2012	East & West

Figure 14 Mountain lion track along fence south of Trousdale

Figure 15. **A) Bobcat track at Farm Hill Road Underpass and B) Deer track at Canada Road Underpass**

Figure 16. **Undeveloped strips adjacent to streets passing under I-280 often had tracks. A) Dirt "sidewalk" at Farm Hill Road Underpass and B) dirt sidewalk at Canada Road Underpass.**

Two types of deer movement behavior were monitored in relation to the highway (I-280) and its surrounding environment: habitat associations and distance from the highway. The habitat types corresponding to all deer locations (Figures 18 and 19) were compared to the distribution of these habitat types within 1 km of the highway (a distance that contained >99% of all deer locations; Figures 18, 19). There were significant differences (P<0.0001) between the proportion of time deer spent in each habitat type and the distribution of the types within 1 km of the highway edge (Figure 20). This was true for both day and night-time locations of deer and was due to deer selecting for various natural habitats (chaparral and mixed-hardwood/conifer) vs. urban/residential areas. Deer seem to select against urban areas (in this case residential neighborhoods), but still occupied them at the same rate (~20%) as the two dominant natural habitat types in the area: coastal oak woodland and annual grassland (Figure 20).

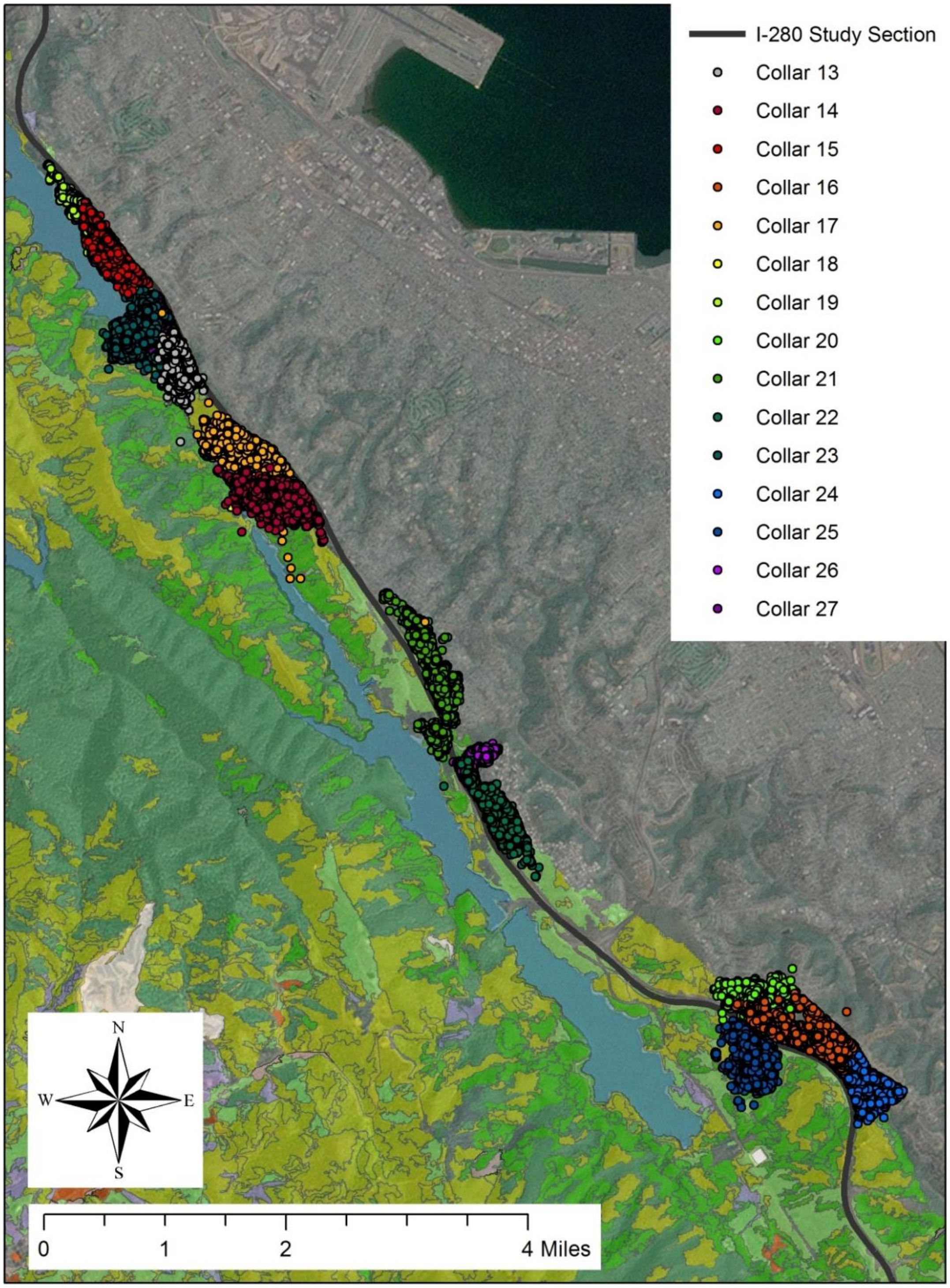


Figure 18. Positions of deer with each numbered collar between December, 2011 and June 2012 (Round 1).

Most of the collared deer stayed within a very circumscribed home range of ~1/2 square mile, with only very occasional movements away from and back toward the home range area (e.g., Collar 17, Round 1 and Collar 13, Round 2).

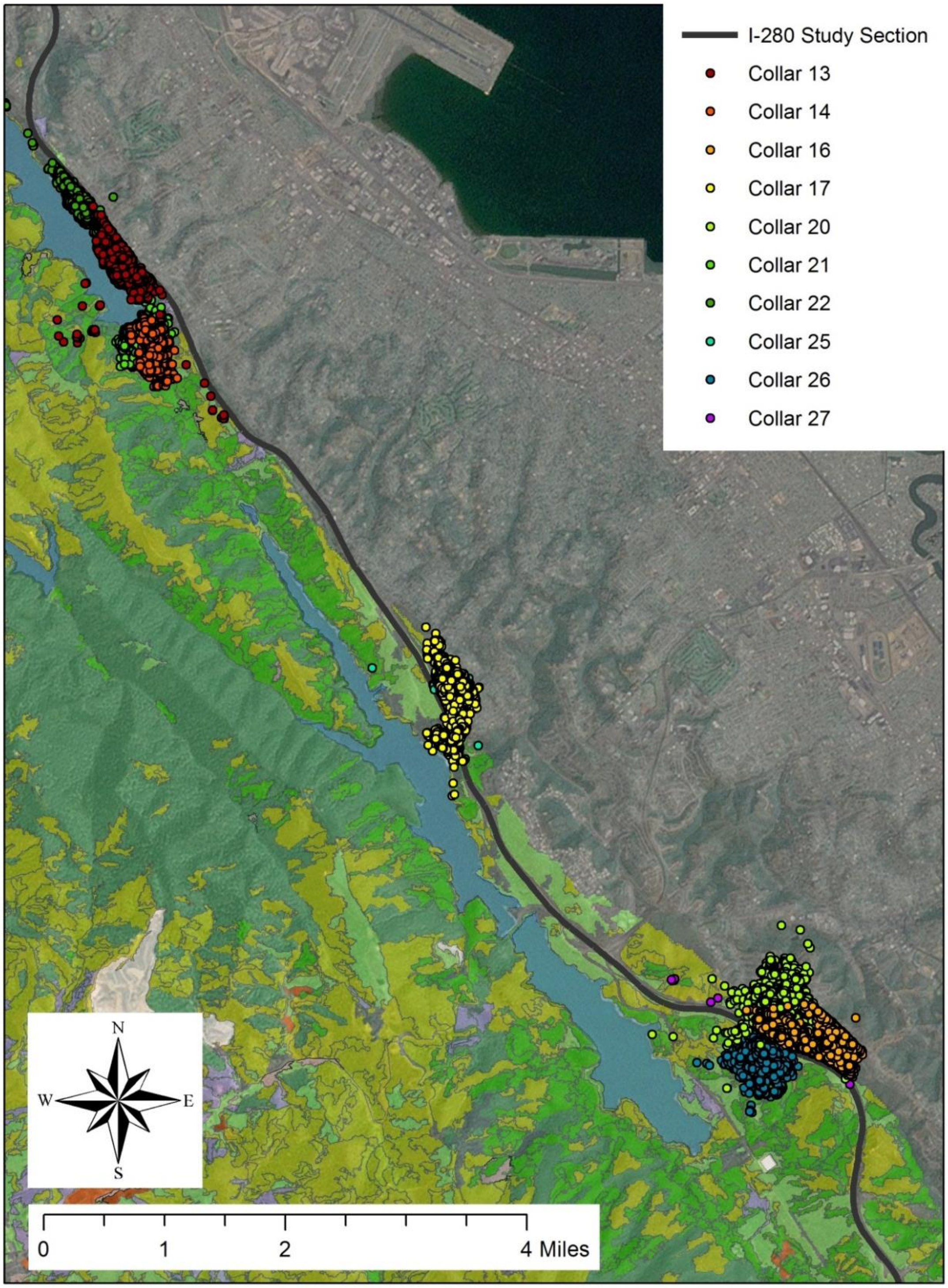


Figure 19. Positions of deer with each numbered collar between July, 2012 and January 2013 (Round 2).

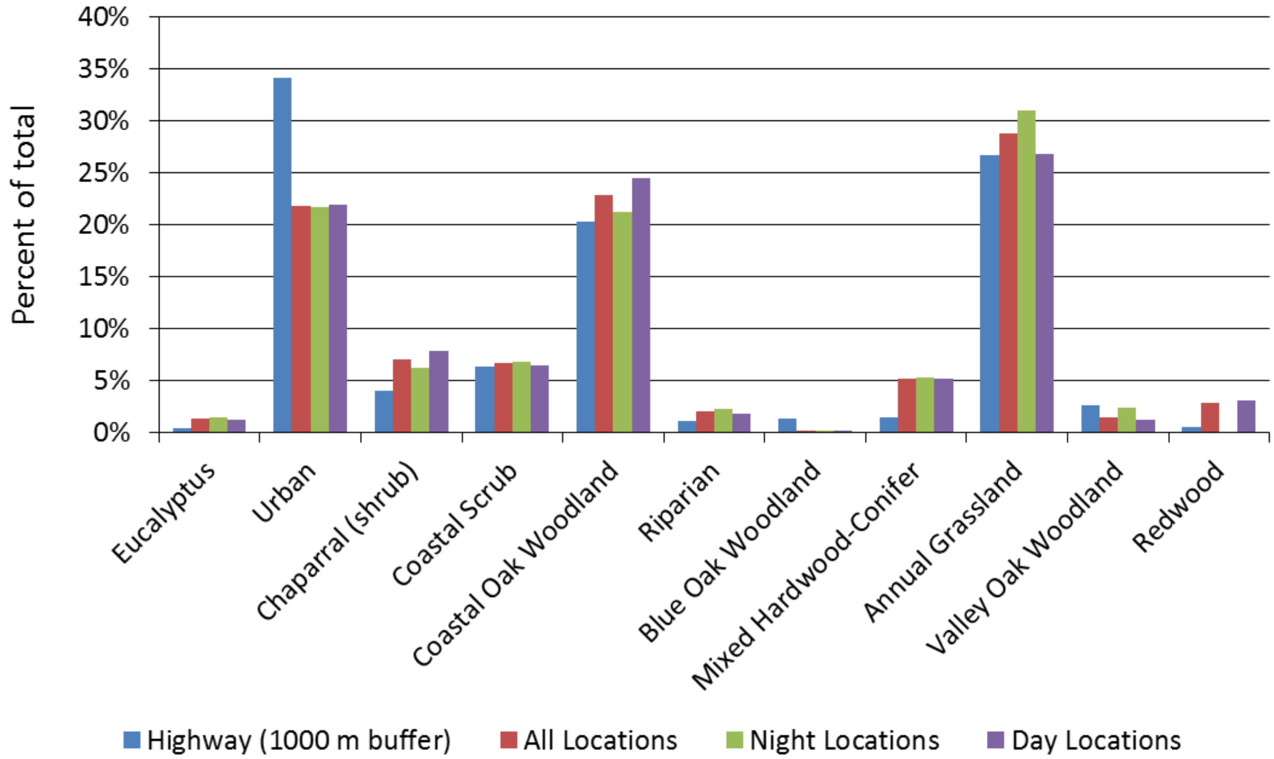


Figure 20 Distribution of habitat types within 1000 m of I-280 within the study area and distribution of "All Locations", "Night Locations" and "Day Locations" of deer within different habitat types in the study area, expressed in both cases as a percent of the total distribution.

Collared deer appeared to be very comfortable within very short distances from the interstate (Figure 21). They also appeared to have very slight, but variable responses to the highway, in response to time of day. Across all deer, there was little variation in distance from the highway edge across the 24-hour day (Figure 22). For individual animals, this ranged from no response to the highway (Collar 13) to a significant diurnal response (Collar 15), where the animal was closest in the morning and furthest in the late afternoon. Both animals represented in the figure were within 1 km of each other and collared at the same time (12/2011 to 6/2012).

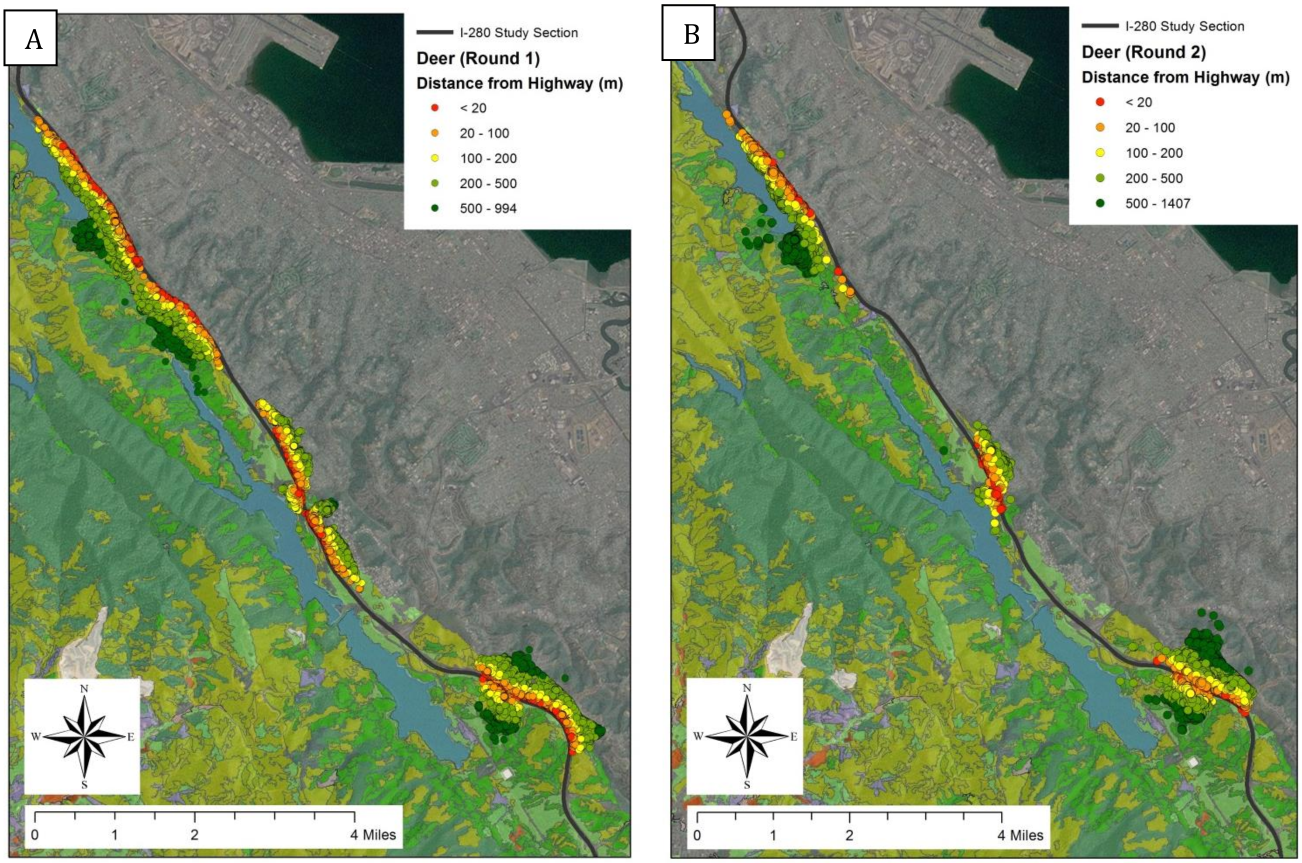


Figure 21 Locations of collared deer expressed as distance from the interstate; (A) north section and (B) south section.

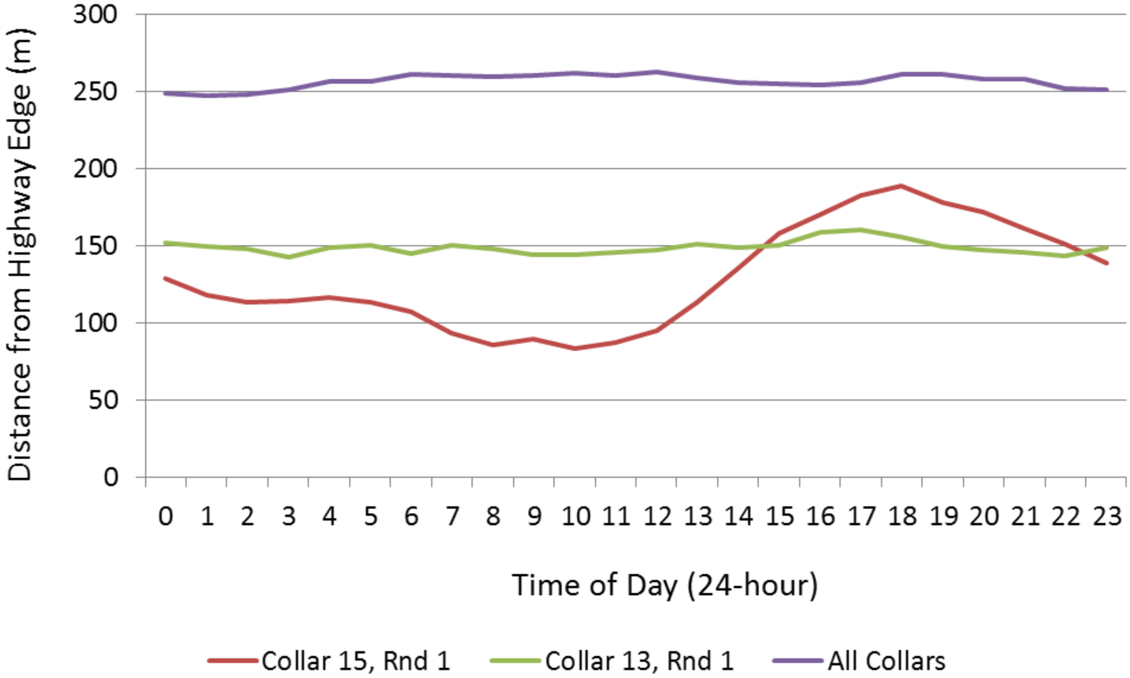


Figure 22. Average distance from the highway right-of-way of collared deer at different times of day. The purple line is the result for all collared deer. The red and green lines are the results for two deer (Collar 15 and 13) collared in the first round of collaring ("Rnd 1").

We also found that 5 collared deer would cross the interstate using 2 of 5 available bridge under-crossings (San Mateo Creek and Vista Point Road), not including the highway 92 interchange bridges (Figure 23). One of the collared deer was eventually hit on the road at the San Mateo Creek bridge, so the availability of these crossings by themselves does not ensure their use for safe passage under the interstate.

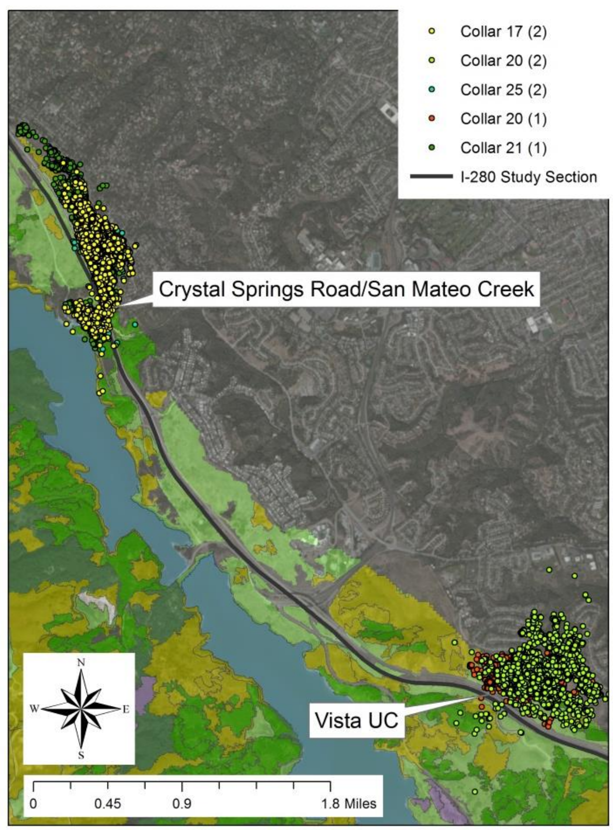
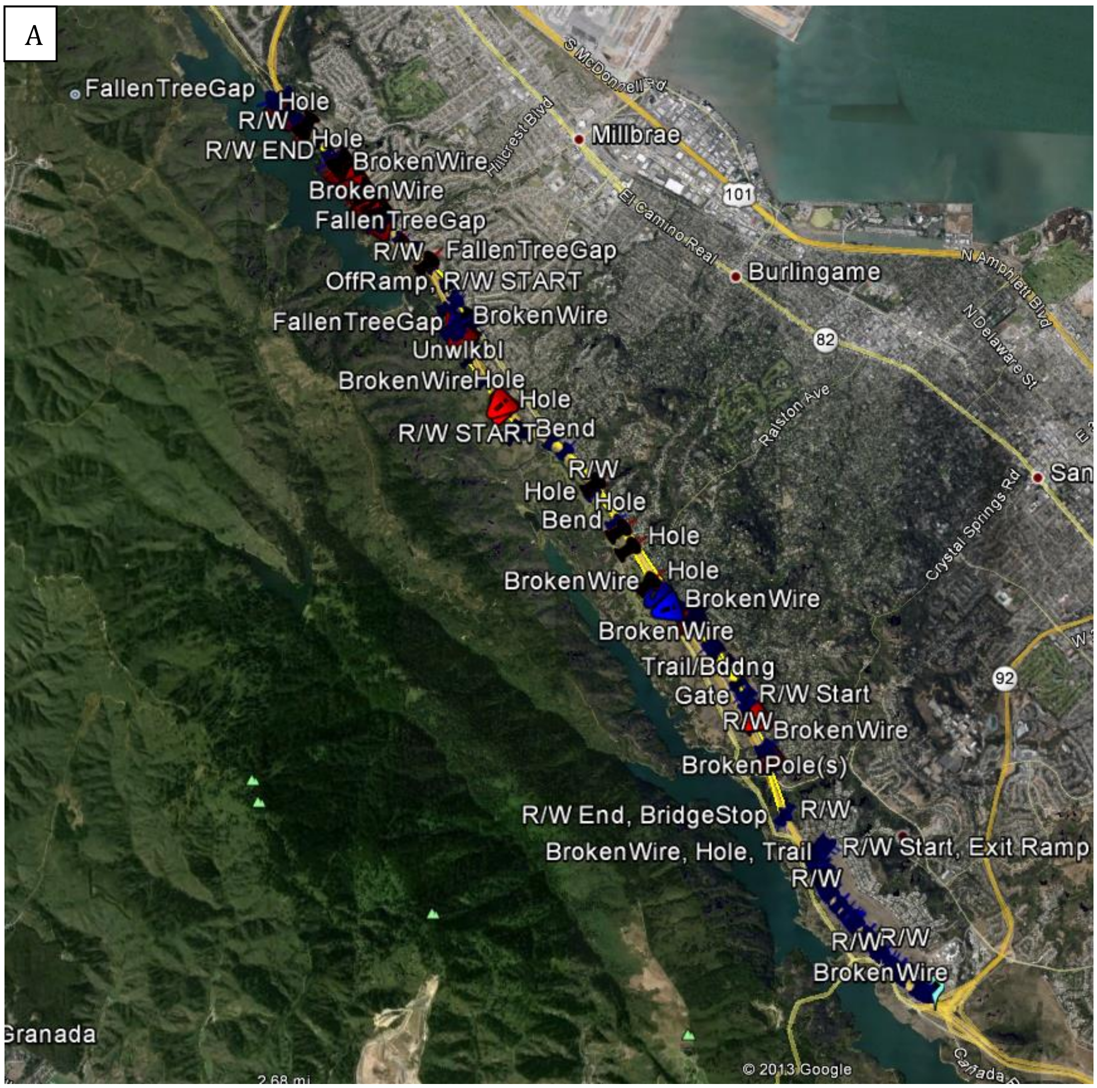


Figure 23. Collar location points for 5 deer that crossed I-280 safely using under-crossings. The number in parentheses indicates whether the deer was collared in Round 1 or 2.

There were segments of fence that were 5-6 feet tall and in good condition. This was especially true at the north end of the study section. There were also segments that were missing, had fallen down, or were severely damaged. These are shown generally in figures 24 A and B and can be more closely examined in the corresponding Excel spreadsheet or Google Earth KML file. Certain sections were not surveyed for various access and safety reasons described in the Methods section.



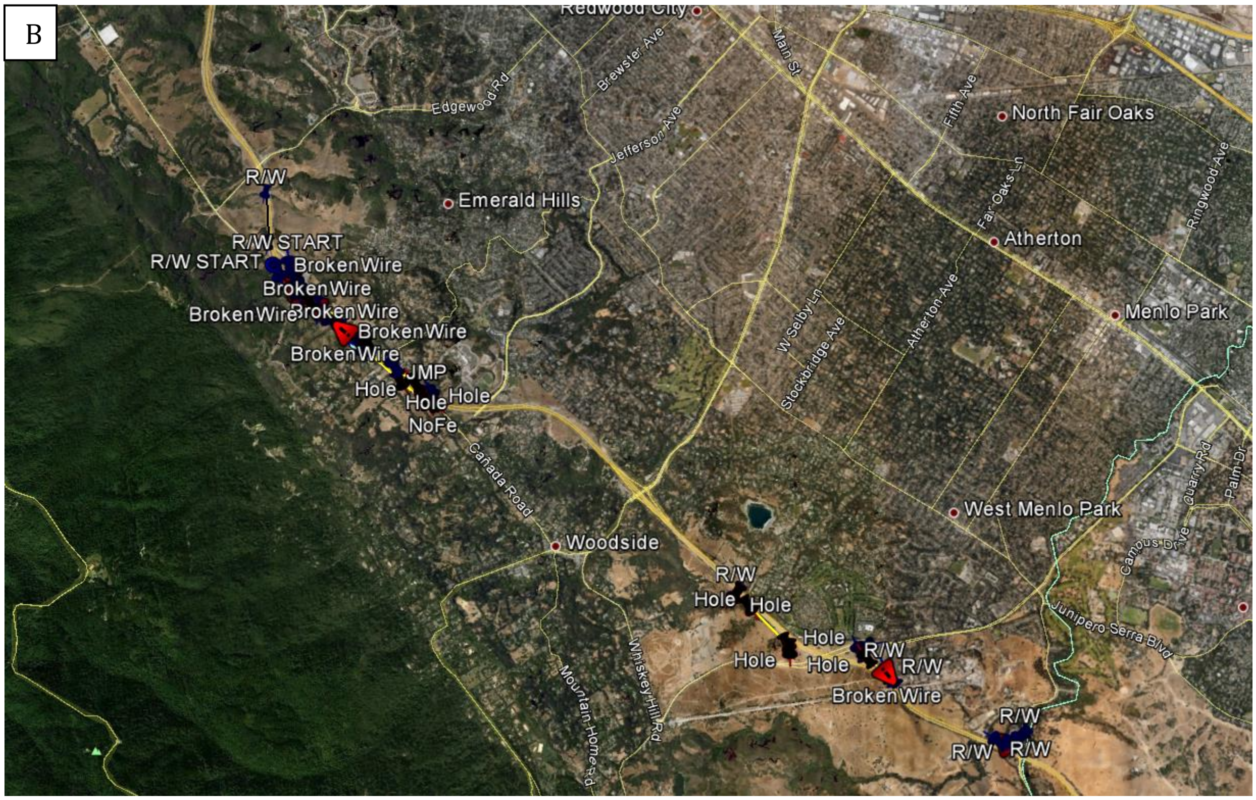


Figure 24. Fence segment end-points and condition assessment for (A) north section and (B) south section.

CONCLUSIONS & RECOMMENDATIONS

Wildlife were found to opportunistically use structures under the interstate not originally designed for wildlife passage. There was a limited diversity of species using these structures and occasionally animals (especially deer) were repelled from the structures. Rate of structure use appeared to be directly related to how often people went through the structures. When more than one person used a structure every 2-3 days, wildlife use dropped precipitously. Wildlife may occasionally cross the surface of busy interstates, but it is likely that most attempts are unsuccessful at the rates of traffic on our study highway. Deer were comfortable spending a lot of time within a few hundred meters of I-280, among any of the available habitat types, including residential neighborhoods. Despite a lack of habitat preference, there were still statistically-significant hotspots for deer-vehicle collisions. There were identifiable hotspots that could be targeted for retrofit to reduce wildlife-vehicle collisions.

Wildlife-vehicle collisions occur at least one every 3 days on I-280, if not more often. Hotspots analysis reveals that there are identifiable regions of the interstate that have greater rates of collision than neighboring regions. According to Caltrans databases (TSN and IMMS), there have been 331 collisions with deer between January, 2005 and July, 2012, or roughly 44/year. Deer are also safely crossing the ROW using under-crossings, and may be safely crossing the surface of the ROW, though the latter behavior has not been recorded. It also appears that one person was killed in 2011 due to colliding with a deer (http://www.thesantaclara.com/news/daniel-strickland-mourned-on-campus-1.2619507). Collisions with deer at highway speeds often results in property damage and injury to drivers (http://www.paloaltoonline.com/news/show_story.php?id=27397). Caltrans was recently sued by a motorcyclist who suffered injury when he collided with a vehicle that had hit a deer. Although the suit was unsuccessful (for the plaintiff), it did raise some relevant points for this study. Most of the plaintiff's case revolved around whether or not the highway was fenced and whether or not Caltrans knew there was a hazard to drivers and failed to do anything about it.

Deer habitat use and movement

Habitat selection was estimated comparing all locations of deer with the availability of different habitat/land-cover types and assumed that all locations were independent of each other. There was habitat/land-cover selection by the collared deer in this study, with chaparral and mixed-hardwood/conifer types being selected for and urban selected against. Because the locations represented deer movement in a series of time-space steps, the locations are actually serially auto-correlated. An improvement over the method used here would have been to analyze deer movement and habitat use using the serial autocorrelation as important information (Martin et al., 2009). When dispersing, deer will respond to major roads, generally by establishing their home range on the side of the road first approached when dispersing, showing some aversion to crossing, but capable of living alongside the road (Long et al., 2010). Our findings are consistent with this behavior, with most collared deer establishing a clear home range, showing no clear aversion response to I-280 and only using a well-vegetated canyon and a seldom-used street under-crossing to cross back and forth under the interstate and avoiding busy street under-crossings. Our findings are also consistent with Found and Boyce (2012) and Gonser et al. (2009), which found that the presence of certain types of vegetation alongside highways could explain the distribution of white-tailed deer-vehicle collisions on the highways. Habitat selection for deer alongside I-280 suggests that the presence of certain vegetation types could partially explain DVC hotspots on this highway.

Deer and other wildlife can and will use certain under-crossing structures, but not others. This relative use seems to be related to the use of the structures by people. We found that if more than one person every few days crosses through a structure, animal (including deer) use will decline. This is consistent with findings for wildlife use of recreation areas (Reed and Merenlender, 2008) and has important implications for management of the existing crossing structures. If the current structures are to be re-managed to encourage wildlife use, then it may be necessary to curtail human use. In many cases, the pedestrian, equestrian and bicycle use of these crossing structures may be considered vital by users. Resolving these multiple uses so that wildlife can pass may be challenging. The alternative to re-managing these existing structures would be to build new wildlife passages.

Conservatively, at least half of the length of the I-280 study area is likely to have collisions between vehicles and any animal, including deer. These areas may be predictable, but what is certainly predictable is that providing directional fencing to encourage deer and other wildlife to usable crossing structures will reduce collisions with vehicles. Directional fencing and accompanying jump-outs (to allow deer escape from the road-side of a fence) have proven to be effective for reducing collisions between deer and vehicles. Directional fencing, electrified mats (Seamans and Helon, 2008), and under-crossings (Hedlund et al., 2004) can be very useful at reducing wildlife-vehicle-collisions. This utility is predictably compromised if the structures and materials are not monitored and maintained. What this means is that animals will enter the roadway if structures are not maintained. In addition, past and future expenditures on driver safety measures like wildlife crossings are better defended with monitoring information in-hand showing effectiveness.

Fencing can vary considerably in price and type. For example, for two recent wildlife underpass projects built by Caltrans on state highways 49 and 50, building under-pass structures, putting up 1 mile of fencing and 2 jump-outs cost $250,000 and $1,600,000 respectively. In contrast, for a mule deer fencing project in Idaho along I-15, adding 4 feet of additional height to an existing 4-foot fence cost <$20,000/mile https://fishandgame.idaho.gov/content/post/i-15-mule-deer-fence-near-pocatello-complete). The fence line along I-280 varies from having no fence, or very degraded fence, to relatively new 6-foot chain link fencing.

FENCE TYPES

Effective deer fencing is at least 8 feet tall, with a maximum fabric mesh size of 8” (Figure 25). Fence posts can be wood or metal and of sufficient strength and frequency to reduce maintenance needs due to downed fencing. In order to reduce the chance of other animals besides deer from pushing through the fence, a finer mesh is often used along the lower 3-4 feet and the foot of the fence is buried (to reduce the chance of animals pushing under) or pushed out underground at least 3 feet (for burrowing animals).

Figure 25. Different styles of fence used to exclude deer (source: http://Iowadnr.gov).

ASSOCIATED STRUCTURES

Fencing is effective in promoting safe passage of animals across a right-of-way when it has associated structures like over or under-passes, jump-outs and cattle-guards. Jump-outs are designed so that animals can jump from the road side of a dirt embankment to ground outside the fence-line (figure 26).

Figure 26. Dirt jump-outs on I-93 (Photo: http://www.fhwa.gov)

Like most highways, I-280 has entry and exit ramps that allow surface street connectivity. If the right-of-way was fenced, then these ramps would permeate the fence, allowing animals to enter the highway surface via the ramps. Cattle-guards are an effective way to reduce or eliminate this entry (Figure 27), making the fence-line effectively impermeable even at the ramps.

Figure 27. Cattle-guard linked to 8-foot fence to prevent deer from entering a road-way around the ends of a fence.

Another method for excluding deer from the ROW via on and off-ramps is by using electrified mats, which can be very effective when correctly deployed (>95%; Seamans and Helon, 2008). These are generally specialized commercial products that use a surface charge to repel deer (Figure 28A). To be effective, these devices must be tied into fence-lines with no space between the fence and the electrified mat (Figure 28B).

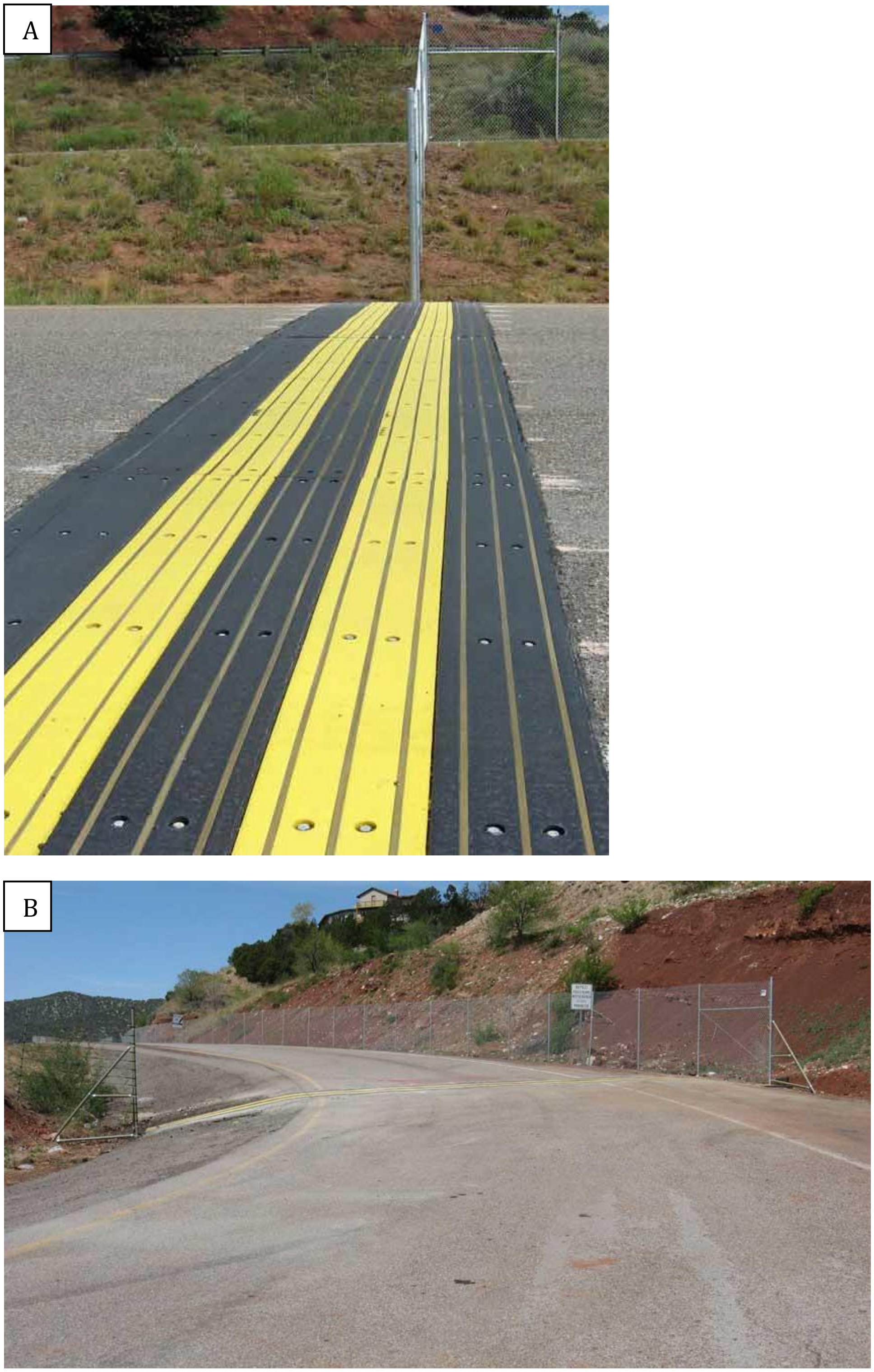


Figure 28. (A) Electrified mat deployed across an asphalt road. (B) Electrified mat associated with adjacent fences.

To be effective, fencing must be tied into landscape or structural features that prevent an animal just going around the end. The availability of "tie-ins" can affect the length of fencing that must be erected. Examples of two potential tie-in points on I-280 are shown in the pictures in Figure 29. Both are places where a 6-foot chain link fence runs into a bridge structure, allowing minor modifications to be added to ensure animals can't work their way around or over the end of the fence. The advantage of places like this is that fencing can be added in stages, rather than all at once.

Figure 29. Fence-lines joining bridge abutments creating tie-in points for deer-proof fencing.

RECOMMENDATIONS

Fence the ~22 miles of I-280 near habitat in ~3 stages to reduce deer and other wildlife access to the ROW surface. Provide crossing pathways within the fenced area for deer and other wildlife so that they don't go around fence-ends and cause more collisions. Use measures such as electrified mat to keep deer from entering the ROW at on and off-ramps. This may cost up to ~$100,000/mile of fencing for new fencing and ~$20,000/mile for enhancing existing fencing to go from 5-6 feet tall to 8 feet tall. Each stage or phase could be completed sequentially over a 3-5 year period. If this is done, then the un-completed areas may still experience wildlife-vehicle collisions and may actually have higher rates of collision because animals that would have crossed at the fenced section are pushed to other places along the interstate to cross. As each phase is completed, its effectiveness could be monitored in order to inform construction of the remaining phases to maximize overall effectiveness. There is no obvious benefit from completing the phases in any particular order except that most collisions occur in the Phase B section, suggesting that this phase should be complete first

<u>Phase A:</u> Place 7.5 mi (each side) of fence between Crestmoor Drive/Skyline Blvd. (35) and the Crystal Springs Rd/San Mateo Creek bridge. On the east side of the interstate, enhance existing 5-6 foot tall fence, where present, to 8 feet tall. On the west side, replace the existing fence in poor condition with new 8-foot tall fence and enhance sections of fence that are 5-6 feet tall (for example along the San Andreas Trail) to create an 8-foot tall fence. Tie the north end of the fenceline to the Crestmoor Rd over-crossing bridge abutment (east and west side) and the south end of the fence line to the Crystal Springs/San Mateo Creek over-crossing bridge abutments. Place electrified mats across the ramps at

Larkspur Dr. (n=4), Hillcrest Blvd. (n=2), Trousdale Dr. (n=4), Hayne Rd. (n=4), and the Rest Area on east side (n=2). Place one deer jump-out per mile of fence (on average), for about 14 total.

Phase B: Place 8 mi (each side) of fence between Crystal Springs Rd/San Mateo Creek bridge and the Canada Rd crossing. On the both sides of the interstate, enhance existing 5-6 foot tall fence, where present, to 8 feet tall. On both sides, replace the existing fence in poor condition with new 8-foot tall fence and enhance sections of fence that are 5-6 feet tall to create an 8-foot tall fence. Tie the north end of the fenceline to the Crystal Springs Rd/San Mateo Creek bridge abutments (east and west side) and the south end of the fence line to the Canada Road under-crossing bridge abutments. Place electrified mats across the ramps at Bunker Hill Dr. (n=4), Ralston Ave/92 West & 92 East (n=4 or 5), Vista Point Rd. (n=4), service Rd. JSO of Vista Point (n=2), trailhead parking lot JNO of Edgewood Rd. (n=2), and Edgewood Rd. (n=4). Place one deer jump-out per mile of fence (on average), for about 16 total.

Phase C: Place ~6 mi (each side) of fence between the Canada Rd under-crossing and the Alpine Rd. or Ansel Ln. under-crossing. On the both sides of the interstate, enhance existing 5-6 foot tall fence, where present, to 8 feet tall. On both sides, replace the existing fence in poor condition with new 8-foot tall fence and enhance sections of fence that are 5-6 feet tall to create an 8-foot tall fence. Tie the north end of the fenceline to the Canada Rd under-crossing bridge abutments (east and west side) and the south end of the fence line to the Ansel Ln. or Alpine Rd. under-crossing bridge abutments. Place electrified mats across the ramps at Canada Rd. (n=2), Farm Hill Blvd. (n=4), Vista Point Rd. (n=4), Woodside Rd. (n=4), Sand Hill Rd. (n=4), and possibly Alpine Rd. (n=4). Place one deer jump-out per mile of fence (on average), for about 12 total.

RESTORING AND MAINTAINING WILDLIFE CONNECTIVITY

Highway crossing structures can be critical connectivity structures allowing safe passage of animals under or over a highway right-of-way. Deer and other wildlife can and will use certain under-crossing structures, but not others. The open-ness ratio (cross-sectional area divided by length) of a structure may determine wildlife use, but actual use may also depend on other structural and environmental attributes perceived by animals to be important. This relative use seems to be related in part to the use of the structures by people. If more than one person every few days crosses through a structure, animal (including deer) use will decline.

Recommendation: Manage under-crossings to reduce human use to <0.1 crossing per day. Provide alternative crossings for people by re-directing people to existing crossings. This could be done in collaboration with SFPUC and County Parks, who manage lands adjacent to potentially useful structures. Our work at the Edgewood County Park trail undercrossing suggests that a large structure could be managed to separate human and animal use within the same structure. This could be accomplished using fences and signs that direct recreational passage to one side and allow animal use on the other side.

Directional fencing, electrified mats, jump-outs, and under-crossings can be very useful at reducing wildlife-vehicle-collisions. This utility is predictably compromised if the structures and materials are not monitored and maintained. What this means is that animals will enter the roadway if structures are not maintained. In addition, past and future expenditures on driver safety measures like wildlife crossings are better defended with monitoring information in-hand showing effectiveness.

Recommendation: Fund maintenance and monitoring of mitigation actions to ensure that they retain their functions and that unforeseen circumstances can be managed as they are discovered. This may cost ¼ FTE Caltrans maintenance staff and ~$20,000/year for a wildlife biologist consultant.

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