PRIORITIZING MITIGATION FOR INTERSTATES USING WILDLIFE MOVEMENT INFORMATION

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ABSTRACT

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. 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.

Three types of wildlife observation data along 2 interstates were used to characterize wildlife movement: wildlife-vehicle collisions (WVC), images from wildlife camera traps at highway under-crossings, 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). Statistically-significant WVC hotspots were modeled using the Getis-Ord Gi* statistic, with Moran's I being used to estimate distance bands. Beginning in July, 2011, camera traps captured still and video images at 4 street underpasses, 1 bicycle over-crossing, 5 railroad under-crossings, 6 culverts, and 10 wildlife trails adjacent to crossing structures. Species diversity and the relationship between wildlife passage and human use of structures were calculated. Twenty four female deer were tracked using GPS collars (Lotek, Inc.) between December, 2011 and January, 2013.

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 at either interstate, which was not a function of camera sensitivity as they could detect movement of small lizards. Collared deer often approached and moved back and forth near the interstate. Only 5 of the 24 collared deer passed back and forth under the highway, all using the same crossing structure, a large vegetated underpass with a minor road.

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 interstates is likely to require 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.

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)

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

Interstate 280

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 23 miles of the I-280 transportation corridor (the study section) is adjacent to high-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.

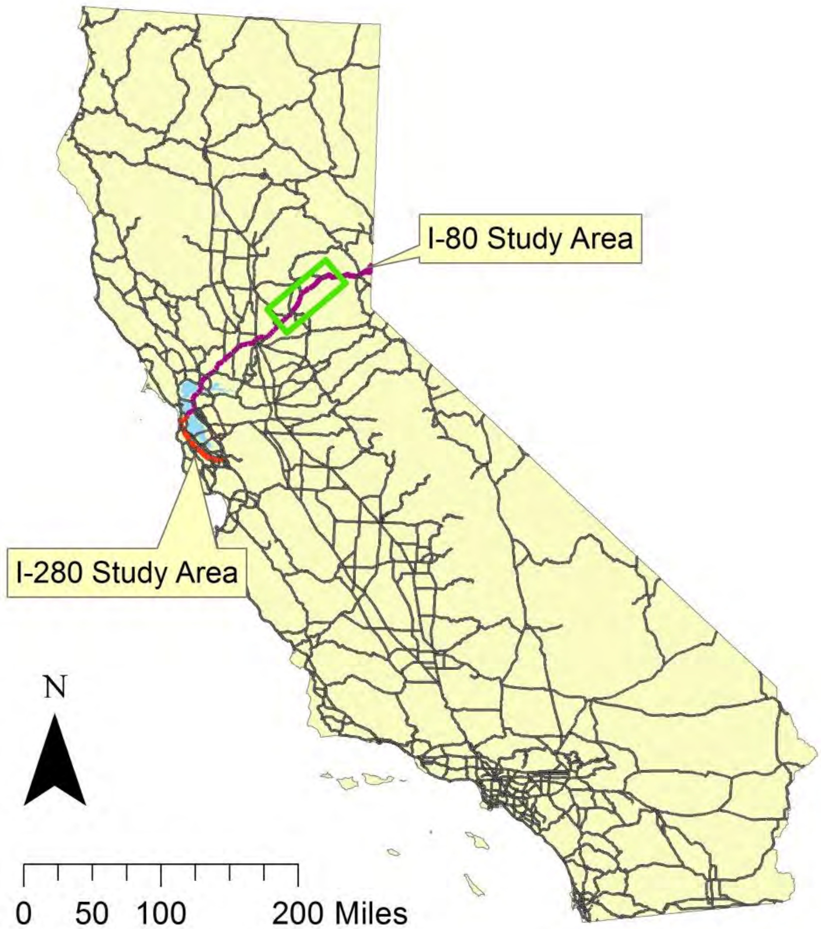


FIGURE 1 **Location map of study areas. The red line corresponds to I-280 and the purple line to I-80. The green box shows locations of wildlife cameras on I-80.**

Interstate 80

This interstate connects the San Francisco Bay Area with Sacramento, Lake Tahoe, Nevada and beyond. It travels from sea level in the Bay Area, bisects the agricultural Central Valley, and crosses the Sierra Nevada mountain range through woodland and conifer forests. Traffic volumes range from >200,000 vehicles/day in the Bay Area to 30,000 vehicles/day at the summit of the Sierra Nevada (Caltrans, 2010).

METHODS

1. Data collection

1.A. Wildlife-Vehicle Collisions

Two types of wildlife-vehicle collision (WVC) data on I-280 were collected: A) Caltrans maintenance records of WVC carcass disposal. Caltrans staff retrieved and provided data from the District 4 database. A separate California Public Records Act request was used to collect data for I-280 held by Caltrans HQ. The data were combined into a single database. B) WVC observations from project staff and volunteer observers driving this stretch of highway; data from the California Roadkill Observation System (http://wildlifecrossing.net/california).

1.B. Wildlife Cameras

Cameras and track plates were placed at potential opportunistic crossing locations under and over I-280 and I-80 frequented by wildlife in order to understand their movement in response to the highways. Remote, motion-triggered wildlife cameras (Cuddeback Capture and 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 85 cameras and experienced ~10% camera loss per year despite using security devices. The data from the cameras were used to estimate the rates of human and wildlife use of structure-location. For I-80, cameras were deployed at 22 positions at 7 locations over a period of 18 months with a range of sampling per location of 21 to 351 days. For I-280, cameras were deployed at 24 positions at 17 locations along the interstate for 18 months with a range of sampling per location of 25 to 366 days. A location refers to a single structure, where a position refers to where a camera was attached and pointed at part of the structure (e.g., opening of a culvert). 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.

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://observation.ice.ucdavis.edu/camera/). 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.

1.C. GPS-Collaring of Deer

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. GPS collars were Lotek Globalstar 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.

2. Data analyses

2.A. 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 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.

2.B. Wildlife Cameras

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.

2.C. GPS 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).

RESULTS

1. Wildlife-Vehicle Collision

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.

I-80 Study Area

We identified several stretches of highway with one carcass/mile-year or greater using either CROS (Figure 2A) or Caltrans (Figure 2B) observations. Most of these observations were of deer, though CROS observations tended to have greater species diversity. The carcass counts per segment length (1/4 to 1 mile) were used to identify locations of WVC clustering, based on CROS (Figure 2C) and Caltrans (Figure 2D) observations. Between the two databases, 13 hotspots were identified for this stretch of I-80, where a hotspot had a high rate of WVC, and/or exhibited a statistically-significant clustering of WVC.

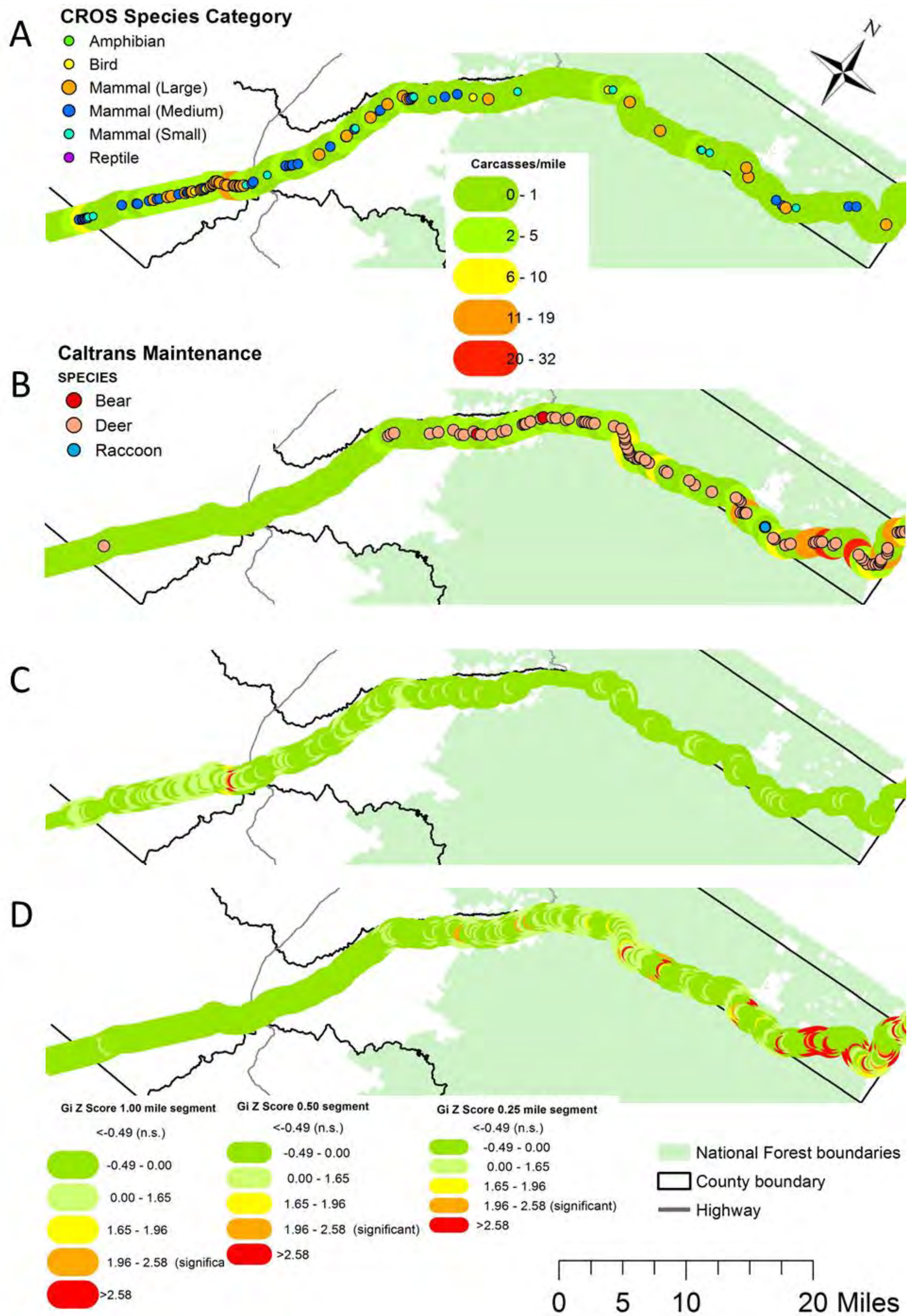
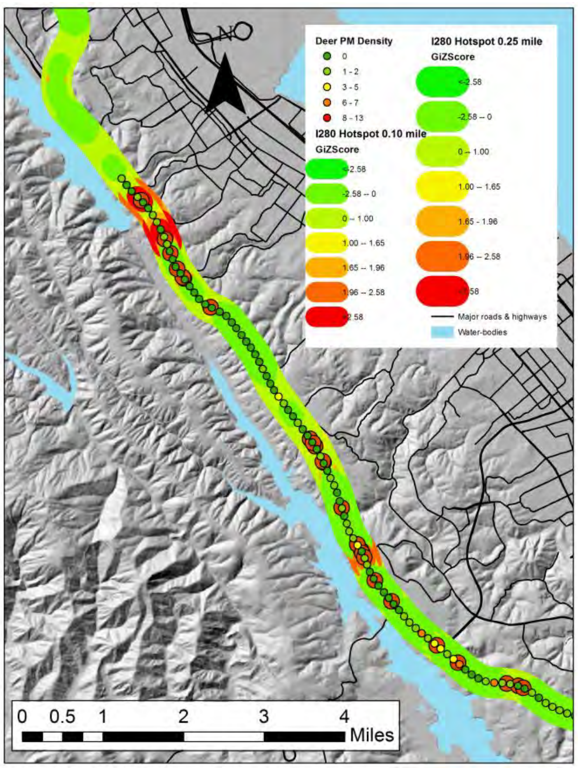

A
CROS Species Category
Amphibian
Bird
Mammal (Large)
Mammal (Medium)
Mammal (Small)
Reptile
Carcasses/mile
0 - 1
2 - 5
6 - 10
11 - 19
20 - 32
B
Caltrans Maintenance
SPECIES
Bear
Deer
Raccoon
C
D
Gi Z Score 1.00 mile segment
<-0.49 (n.s.)
-0.49 - 0.00
0.00 - 1.65
1.65 - 1.96
1.96 - 2.58 (significa
>2.58
Gi Z Score 0.50 segment
<-0.49 (n.s.)
-0.49 - 0.00
0.00 - 1.65
1.65 - 1.96
1.96 - 2.58 (significant)
>2.58
Gi Z Score 0.25 mile segment
<-0.49 (n.s.)
-0.49 - 0.00
0.00 - 1.65
1.65 - 1.96
1.96 - 2.58 (significant)
>2.58
National Forest boundaries
County boundary
Highway
0 5 10 20 Miles
N

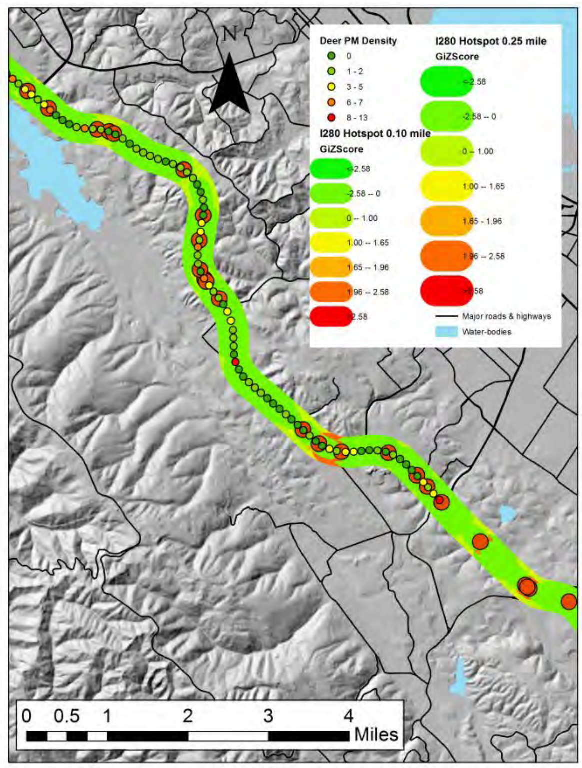
FIGURE 2 Locations of WVC hotspots based on carcass counts (A,B) and spatial clustering (C,D). The WVC carcass data were 3 years of data from the California Roadkill Observation System (A,C) and 17 years of data from Caltrans (B,D). The GiZ score in C & D refers to the Getis-Ord statistic of significance, where values >1.96 indicate significant spatial clustering.

I-280 Study Area

Four statistically significant hotspots were identified on I-280 for collisions involving any animal (figure 3A,B). The significance of these hotspots is that they are places different from their neighbors, not that non-hotspots lack significance in terms of number of collisions. Hotspots were determined using the CROS data (figures 2 and 3). These hotspots were compared with a summary by Caltrans of deer carcasses per 1/10 point mile and deer carcasses reported in CROS (figure 4). 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.



A



B

FIGURE 3 Locations of WVC hotspots based on deer carcass counts by post-mile ("Deer PM Density") and spatial clustering of all WVC. 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.

Deer-vehicle collisions (DVC) are a special sub-set of WVC because of the risk posed to drivers and vehicles from the collision. DVC 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 on this interstate.

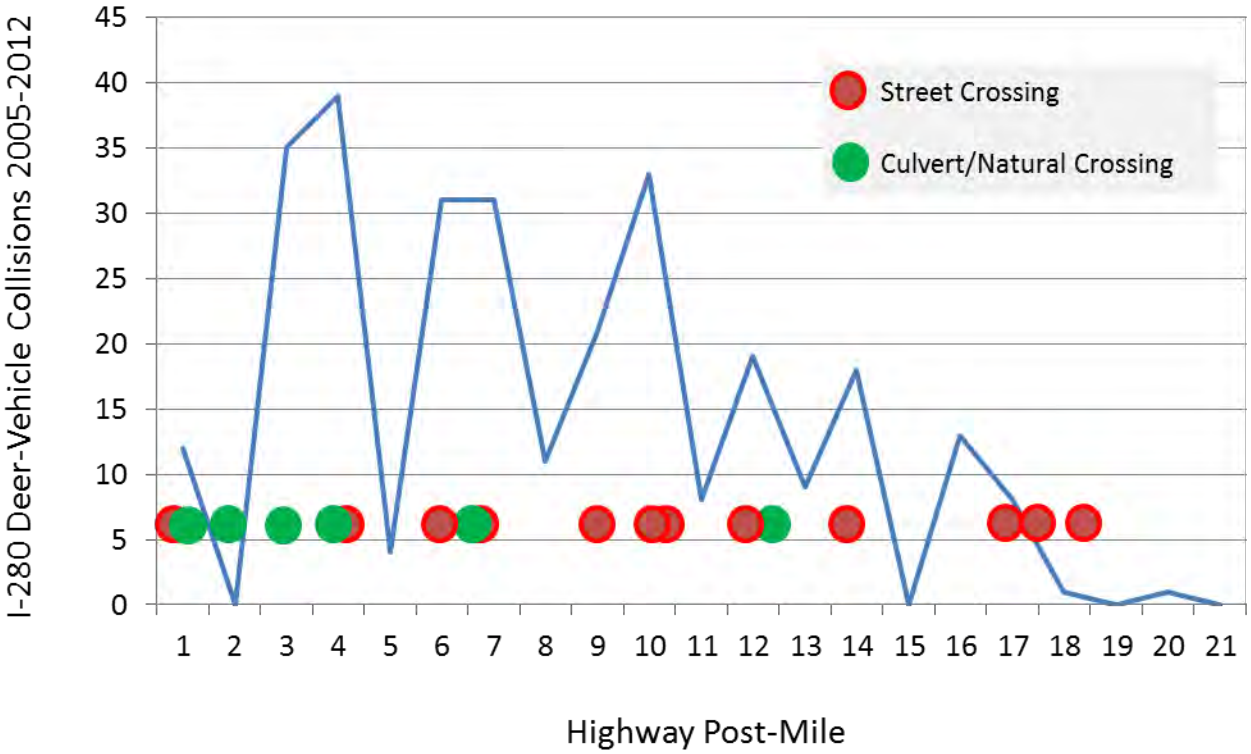


FIGURE 4 Comparison of number of deer-vehicle collisions (DVC) on I-280 per post-mile and the approximate location of street, culvert, and natural-bottomed crossing structures.

2. Deer Movement

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 were compared to the distribution of these habitat types within 1 km of the highway (a distance that contained >99% of all deer locations). There was no significant difference 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 5). There was no difference between habitats occupied in the day vs. night. 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 5).

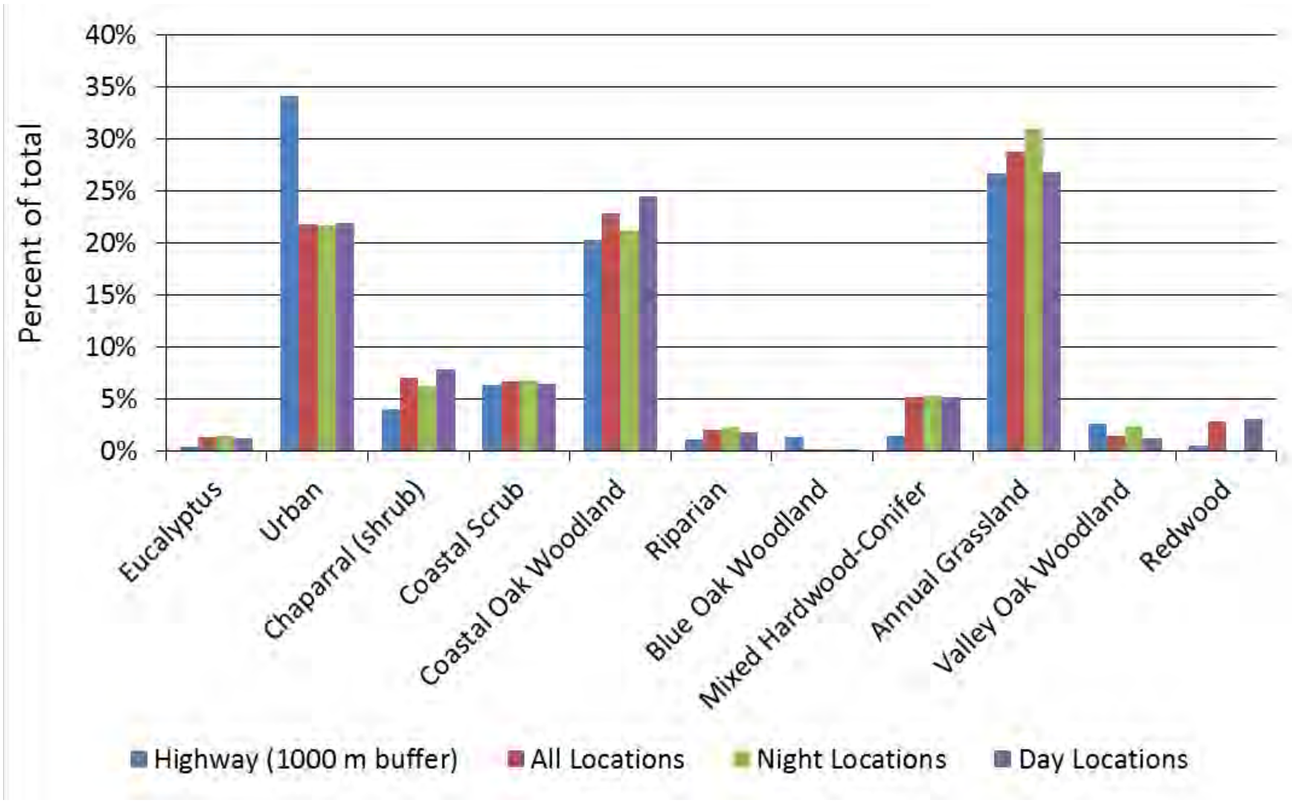


FIGURE 5 Distribution of habitat types within 1000 m of I-280 within the study area and distribution of "All Locations", "Night Locations" and "Day Locations" of deer within different habitat types in the study area, expressed in both cases as a percent of the total distribution.

Collared deer appeared to 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 6). 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).

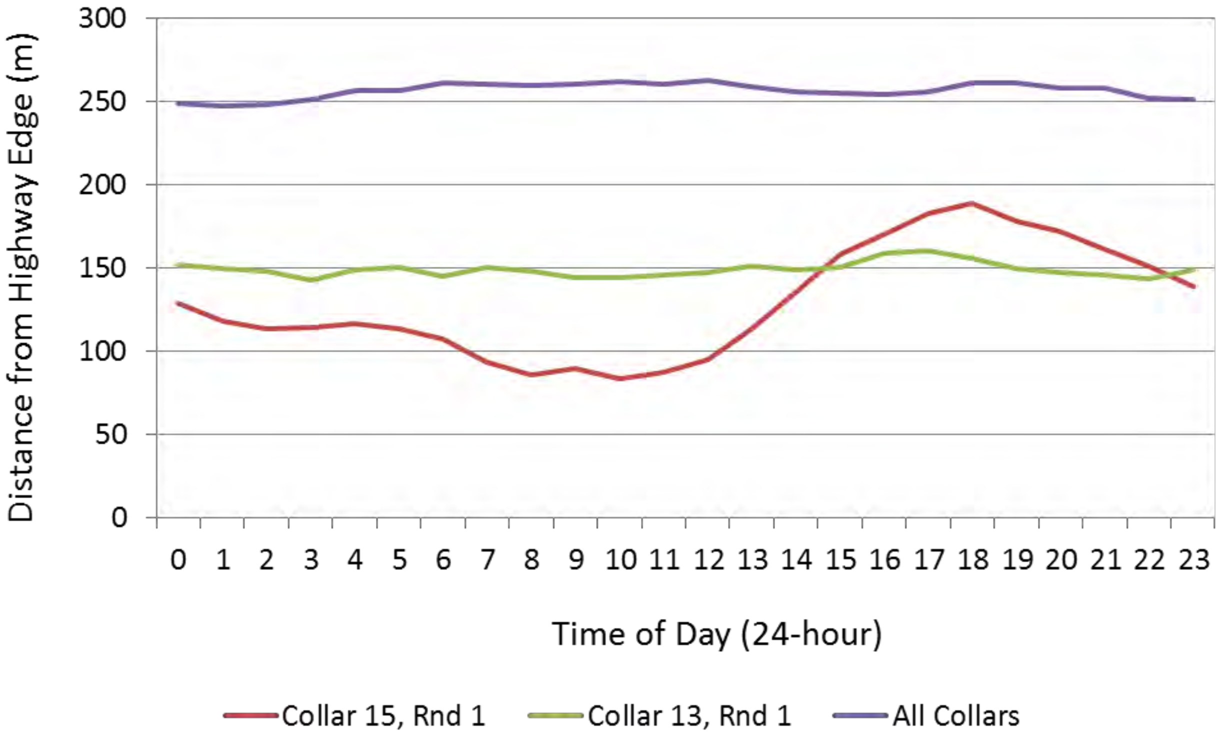


FIGURE 6 Average distance from the highway right-of-way of collared deer at different times of day. The purple line is the result for all collared deer. The red and green lines are the results for two deer (Collar 15 and 13) collared in the first round of collaring ("Rnd 1").

3. Wildlife Cameras

Animals were identified in pictures from cameras at under-crossings, culverts, and on animal trails near the interstates. 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 and a 5-foot diameter culvert under I-80. The lowest rates were for a 10-foot box culvert (under I-280) and a railroad under-crossing (I-80). 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.

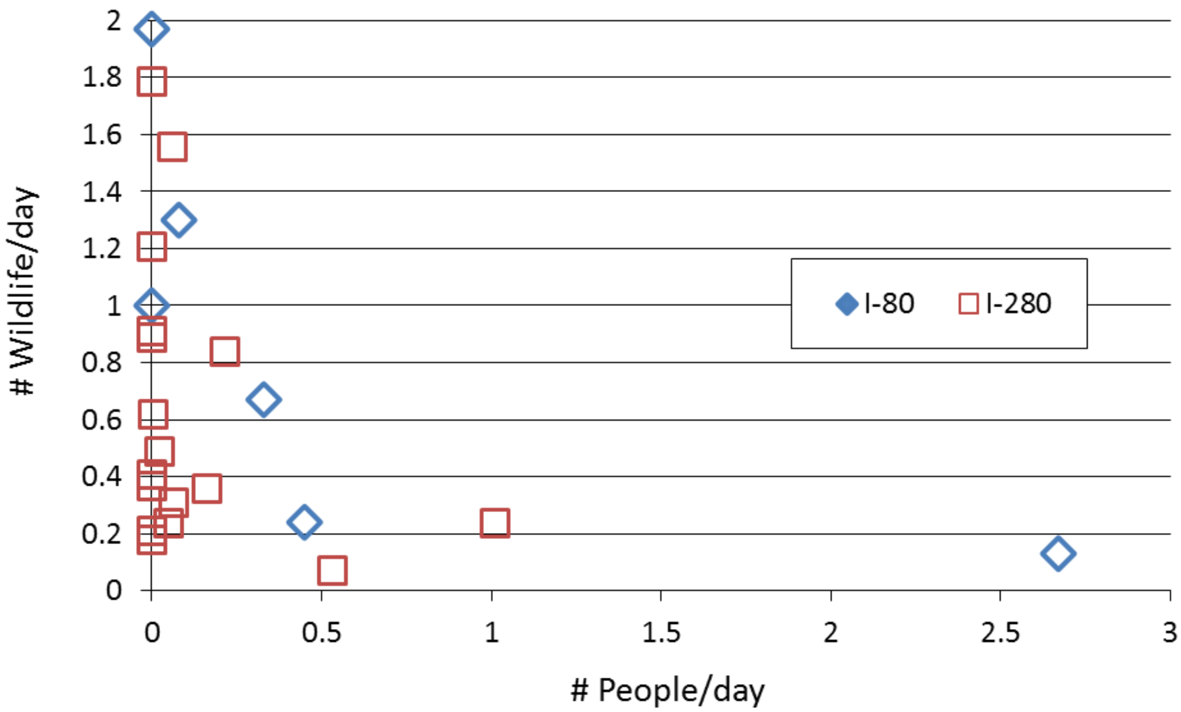


FIGURE 7 Comparison of wildlife rate of structure use with human use of the same structures. Each symbol represents a different structure along each of the interstate study areas.

DISCUSSION AND RECOMMENDATIONS

Wildlife were found to opportunistically use structures under interstates 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 highways. 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. For both interstate, there were identifiable hotspots that could be targeted for retrofit to reduce wildlife-vehicle collisions.

Deer habitat use and movement

Habitat selection was estimated comparing all locations of deer with the availability of different habitat types and assumed that all locations were independent of each other. There was no obvious habitat selection by the collared deer in this study. 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 showing no clear aversion response to I-280 and only using a well-vegetated canyon to cross back and forth under the interstate and avoiding street under-crossings. Our findings are not as 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. Lack of habitat selection for deer alongside I-280 and the lack of association of identified hotspots on I-280 with specific vegetation types (data not shown) suggests that vegetation alone may not 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. Several of the structures were railroad under-crossings, which were commonly, but illegally, used by many people. 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.

I-280 Study Area

Wildlife-vehicle collisions occur at least once 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. Widlife are also safely crossing the ROW using certain under-crossings, and may be safely crossing the surface of the ROW, though the latter behavior has not been recorded. On average, 3.7 mule deer were killed per month (2005 – 2012) in collisions with vehicles on I-280. This rate is similar to rates found for highways and interstates in Washington state (Wang et al., 2010). It also appears that one person was killed on I-280 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.

Conservatively, at least half of the length of the I-280 study area is likely to have collisions between vehicles and any animal. About ¼ of the length of the area appears to be likely to have collisions between deer and vehicles. 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.

I-80 Study Area

Interstate 80 traverses one of the most important and iconic features in California, the Sierra Nevada. This study placed cameras at over half of the very few I-80 structures on the western slope of the Sierra Nevada, including all large railroad crossings. There was frequent wildlife use at structures without much or any human activity. However, the relatively few structures and the low rate of use at structures with more human use suggests that I-80 may not be very permeable to wildlife. This is reflected in the low diversity of species observed using crossing structures. This means that although the existing set of structures provides some benefit in terms of wildlife permeability, it may not be adequate to prevent biodiversity loss and population fragmentation. There are identifiable areas of high WVC rates and statistically-significant spatial clustering throughout the Sierra Nevada stretch of I-80. These are areas that could and should receive retrofitting by Caltrans to improve wildlife passage and reduce risk to drivers.

Recommendations

1) Fence the 22-miles of I-280 near habitat in ~3 stages to reduce deer and other wildlife access to the ROW surface. Fence hotspots and areas of high rates of WVC of I-80. 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.

2) Manage under-crossings to reduce human use to <0.1 crossing per day. Provide alternative crossings for people through re-directing people to existing crossings.

3) 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.

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BIOGRAPHICAL SKETCHES

Fraser Shilling 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.

Tanya Diamond is a wildlife biologist who uses wildlife cameras, tracking, and scat identification to study connectivity and wildlife movement. She and a partner own Connectivity for Wildlife LLC, which helps local transportation and conservation agencies to plan for wildlife protection in the Central California Coast region.

Kathryn Harrold is a wildlife-biologist-in-training who was largely responsible for the I-280 study coming into being. As a commuter she noticed a lot of animals dying from collision with vehicles along I-280. She successfully pursued the funding for the project and is the project coordinator.

Iara Lacher is a graduate student at UC Davis in Ecology. Her major focus is on the effects of climate change on vegetation. Her previous training is in conservation planning and analysis.

David Waetjen is a researcher and programmer at UC Davis. He received his PhD from UC Davis in the Geography Graduate Group in informatics. He designs web-based informatics systems for multiple research centers at UC Davis.

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