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Impact of Wildlife-Vehicle Conflict on California Drivers and Animals

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UCDAVIS
ROAD ECOLOGY CENTER

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Using observations of reported traffic incidents and carcasses the Road Ecology Center estimates the total annual cost (2017) of wildlife-vehicle conflict (WVC) in California to be at least $307 million, up 11% from 2016. The estimated cost could be as high as $600 million if accidents that are claimed to insurance companies (but un-reported to police) were included. This report includes maps of WVC hotspots, discusses impacts to wildlife and people from WVC, and presents new tools to help organizations and individuals use this information. Projects to reduce WVC can be the most effective of any safety project, with effectiveness often >90%.

Data Sharing/Collaboration: We are always happy to share data and map outputs for people interested in reducing wildlife-vehicle conflict for driver safety and/or wildlife conservation. We receive requests from highway planners, fish and wildlife scientists, students, and non-governmental organizations on a weekly basis. We can typically meet data requests for specific highways, counties, etc., but please keep in mind that this is an unfunded effort of the Road Ecology Center, so we will try to get back to you within a few days.

We have developed a globally-unique web-tool to visualize WVC incidents in CA. It shows WVC hotspot areas throughout CA and a real-time display of WVC events. You can find the website here: https://roadecology.ucdavis.edu/hotspots.

This report provides an overview of wildlife-vehicle conflict (WVC) hotspots on California highways between 2015 and 2017, inclusive, based on a combination of traffic incidents involving wildlife that were recorded by the California Highway Patrol (CHP) and carcass observations reported to the California Roadkill Observation System (http://wildlifecrossing.net/california). Analytical details are provided here and are also available from Fraser Shilling (fmshilling@ucdavis.edu) upon request. This report also introduces a new, public web-system that allows the public and transportation agencies to view our scientific results for both legacy/long-term hotspots analysis and real-time tracking of WVC incidents.

Photo acknowledgement

Bighorn Sheep – BighornSheep Institute

Data collection acknowledgements

We appreciate the support from the National Center for Sustainable Transportation (using USDOT funding) for development of the automated wildlife-vehicle conflict hotspot tool described here and elsewhere. This and previous reports and the analyses contained within would not have been possible without the concerted and coordinated efforts of hundreds of volunteer roadkill observers over the last 9 years who contribute to the California Roadkill Observation System (CROS, http://wildlifecrossing.net/california). Through their endeavors, they have so far (9/2018) collected >58,000 observations of >420 species, representing one of the largest and most comprehensive wildlife monitoring programs in California. Their accuracy rates for species identification are >97% and have measurably high locational accuracy (median <±13 meters). For scientific papers describing our roadkill/WVC work, see our published work cited below and at the end of this report (you can paste the "doi" value into a browser and access the papers). The report also benefited from the efforts of many unknown law enforcement personnel who described traffic incidents in enough detail that we can use their observations to help plan for reduced wildlife-vehicle conflict.

CROS is 9-Years Old, Published, & Globally Linked

The Road Ecology Center at UCD is happy to announce that CROS passed its 9th birthday, and during this period, the volunteers have assembled an (ongoing) important dataset which can benefit California wildlife and drivers in the decades to come. We have published our data and findings in the peer-reviewed journals Ecological Informatics, Nature Conservation, and Frontiers of Ecology and Evolution, covering the technical details of the project, including the accuracy of volunteer observations. Finally, we have partnered with other similar systems around the world in the Globalroadkill.net project (http://globalroadkill.net).

Citation for CROS: Waetjen DP and Shilling FM (2017) Large Extent Volunteer Roadkill and Wildlife Observation Systems as Sources of Reliable Data. Front. Ecol. Evol. 5:89. doi: 10.3389/fevo.2017.00089

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UC Davis Road Ecology Center
Fifth Annual Special Report on the Impact of Wildlife-Vehicle Conflict (WVC) on California Drivers and Animals

Top 5 Recommendations

1) **Systematically collect and share data.** The state data assembled here were not collected with the purpose of studying wildlife-vehicle conflict, the volunteer data were. California agencies should collect and share data about wildlife-vehicle conflict to help inform decision-making about this important conservation and safety problem. We are open to partnering with Caltrans, California Department of Fish and Wildlife and others to accomplish this.

2) **Require collection and analysis of wildlife-vehicle conflict data for highway/road projects**, **before they are approved and funded.** Transportation and wildlife agency biologists have very little data upon which to base decisions for projects impacting wildlife. Highway projects that are likely to increase WVC can be built because these data are not required.

3) **Protect driver safety and wildlife by building WVC-reduction projects.** Very few driver safety projects have the overall effectiveness that WVC reduction projects do. There are hundreds of places on state highways and major roads where WVC is a priority, but statewide only 2-3 projects are built per year. Ten times that rate would make a dent in the apparent risk to both drivers and wildlife.

4) **Form new partnerships** among University and NGO scientists, citizen groups, and local agencies interested in reducing WVC impacts. Local and statewide partners can help advocate for diversion of transportation funds to improve ecological sustainability of transportation.

5) **Systematically evaluate how well we are doing with WVC reduction** so that we can keep improving. As we plan and build WVC reduction, we should transparently monitor reduced driver injuries and death and use of the structures by wildlife.

Introduction

Using California state data on traffic incidents, the Road Ecology Center has mapped stretches of California highway that are likely to be continuing hotspots for wildlife-vehicle conflicts (WVC). Animals entering roadways are often killed and pose a hazard to drivers, who may collide with the animal, or try to avoid the animal and have an accident suffering vehicle damage, injury, and even death. We estimated the total annual cost to society from >6,600 WVC incidents in California on state highways and a small proportion of major roads to be ~$307 million for 2017, which is an 11% increase compared to 2016. **It is important to note that this**

report does not cover ALL incidents in California, just the ones reported by the CHP and California Roadkill Observation System (CROS). State Farm Insurance Co. estimated that California had >23,000 claims/year for collisions with wildlife in 2015-2016 (https://newsroom.statefarm.com/download/234883/allstates2015-16deerstats-finalpdf.pdf), which is >3 times the rate we describe here and if included, would result in a total cost to society of ~$600 million/year, which would be similar to costs in other states where total costs have been evaluated (e.g., VA, Donaldson, 2017). In addition, we counted 268 injury accidents in the CHP data we used, which is less than the 383 injury accidents Caltrans reported using CHP data in their press release for the 2018 press release (http://www.dot.ca.gov/paffairs/pr/2018/prs/18pr072.html). So, our study under-estimates the injury portion of the total cost of these types of accidents by ~1/3. This contrast also points to the need for a standardized system for California to collect and report these data. Wildlife populations may suffer significant losses due to collisions and highways with high rates of WVC may cause ripple effects into surrounding ecosystems. In addition, animals are injured during collisions, which is damaging to the animal and potentially traumatic and deadly to drivers.

By identifying stretches of highway where WVC are more likely, the Road Ecology Center is assisting Caltrans and other responsible entities in developing mitigation to protect drivers and wildlife populations. Measures with proven effectiveness include building fencing and over/under-passes along priority highways to allow the safe passage of wildlife across highways and reducing speed limits in protected wildlife habitat. Using CHP data, we have found records of >6,600 reported accidents per year on California highways involving deer and other wildlife. We estimate that there are another few thousand with horses, cows, sheep and goats.

For the third year analyzing CHP data, we have determined rates and locations of both animal carcasses and reported traffic incidents. These incidents could be reports of animals running across the road, collisions with animals (primarily deer), or accidents resulting from people swerving to avoid a collision with an animal in the road. Because deer activity adjacent to highways is correlated with rates of collisions with deer (Donaldson et al., 2015), we included reports of live animals on or near highways (~10% of all reports). Our analyses include identification of geographical hotspots and calculated costs to the public from vehicle damage, injury and even death. This information shows where there are problems and should help in developing safety projects to fix these known problem areas.

The following sections include maps of the distribution of WVC densities, projected costs of WVC and hotspots along state highways and other roadways. The densities of WVC reported are the minimum for each highway segment and do not represent actual rates, which are likely to be much higher. By significantly increasing the systematic treatment of these hotspots and stretches of highway with high rates of collisions, Caltrans and other entities can contribute cost-effectively to driver safety and improve the environmental sustainability of state highways.

Methods

Traffic Incidents

Records of traffic incidents between February 2015 and December 2017 were obtained from state databases of traffic incidents (e.g., emergency responses to crashes), included in our customized "California Highways Incident Processing system" (CHIPs), and coded according to severity of the incident for the drivers/vehicles and for the animals. For this ~3 year period, we separated the ~19,800 records of wildlife-vehicle collisions from the ~2.5 million traffic incidents using customized term queries (e.g., for "deer" AND "buck" AND "doe" AND "fawn"). We reviewed each record for information about fate of the animal, fate of the driver, type of accident (collision vs. swerve), and vehicle damage. Location and date/time information were from the incident record.

The California Roadkill Observation System project (http://wildlifecrossing.net/california) includes past and current participation by over 1,000 volunteer-scientists, including several hundred academic, agency, and NGO biologists and natural historians (Waetjen and Shilling, 2017). More than 56,000 WVC observations were contributed to the website by volunteers between August 2009 and the end of 2017 and by Caltrans Maintenance staff for the period 1987 to 2007. We selected recent observations of large-animal carcasses (last three years) and combined these observations with the CHP crash data. We carefully controlled for duplicates, which were only rarely found because animal carcasses from crash incidents were usually collected fairly quickly by Caltrans.

The carcass observations and traffic incidents were used in a geographic information system (GIS) to identify stretches of highway where WVC occur more frequently (high density) and places where there are statistically-significant clusters of WVC (hotspots; Shilling and Waetjen, 2015). Density was calculated as number of incidents/mile and by using the Kernel Density Estimator (KDE) tool in ArcGIS. Hotspots were identified using the spatial autocorrelation test Getis-Ord for 1 mile state highway segments. Specific methods are included in a methodology appendix. Estimates of costs to society of incidents were calculated using the nature of the incident (e.g., "minor injury") and coefficients for the average cost of these types of incidents used by the US Department of Transportation (USDOT, 2013) and in published literature (Huijser et al., 2009) and technical reports (Cramer et al., 2016).

Major Findings

Statewide Carcass Observations

The maps below show >56,000 observations of animal carcasses on local roads and state highways (Figure 1). These are not the total roadkill that occurred, just the ones that people saw and reported to the California Roadkill Observation System (CROS) between 2009 and 2017.

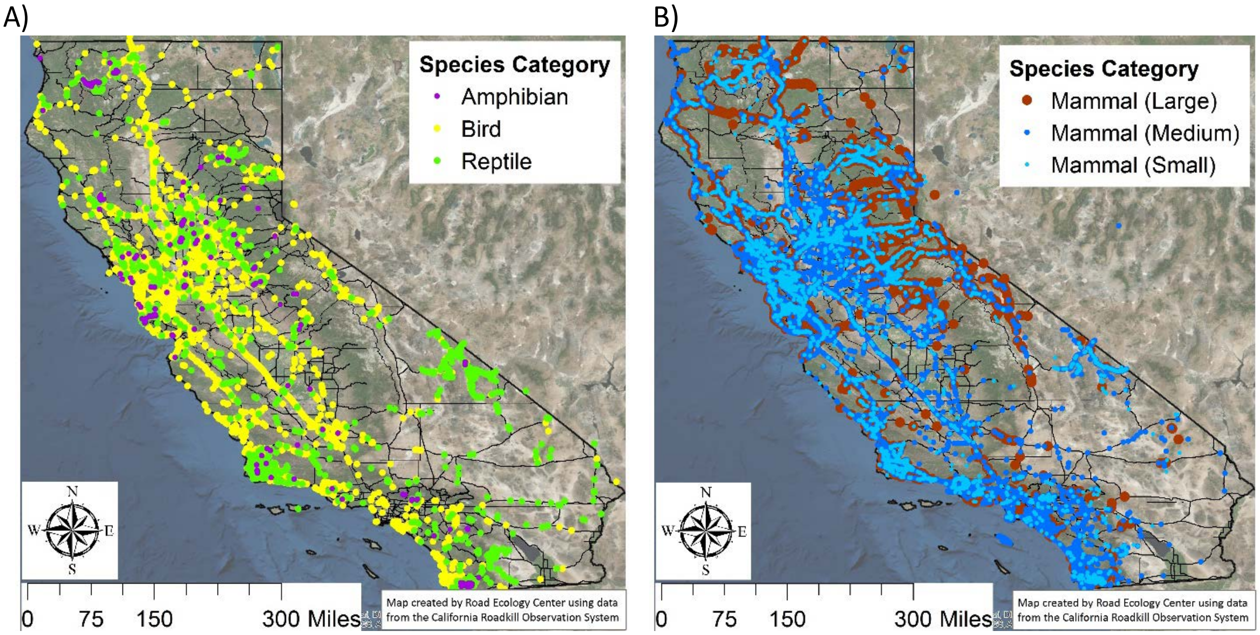


Figure 1. Carcass observations for (A) amphibians, reptiles, and birds; and (B) mammals.

Statewide Highway Traffic Incidents

There were >2 million traffic incidents (of all types) across California reported to the California Highway Patrol in 2015-2017. Of these, about half were collisions and more than 19,800 involved wildlife, including reports of animals standing next to, standing in, or running across roadway lanes, collisions with large animals, and swerving to avoid collisions, resulting in a crash (Figure 2, Wildlife vehicle conflicts). The Fall is the most likely time for WVC, due to increased movement related to mating seasons and seasonal migration.

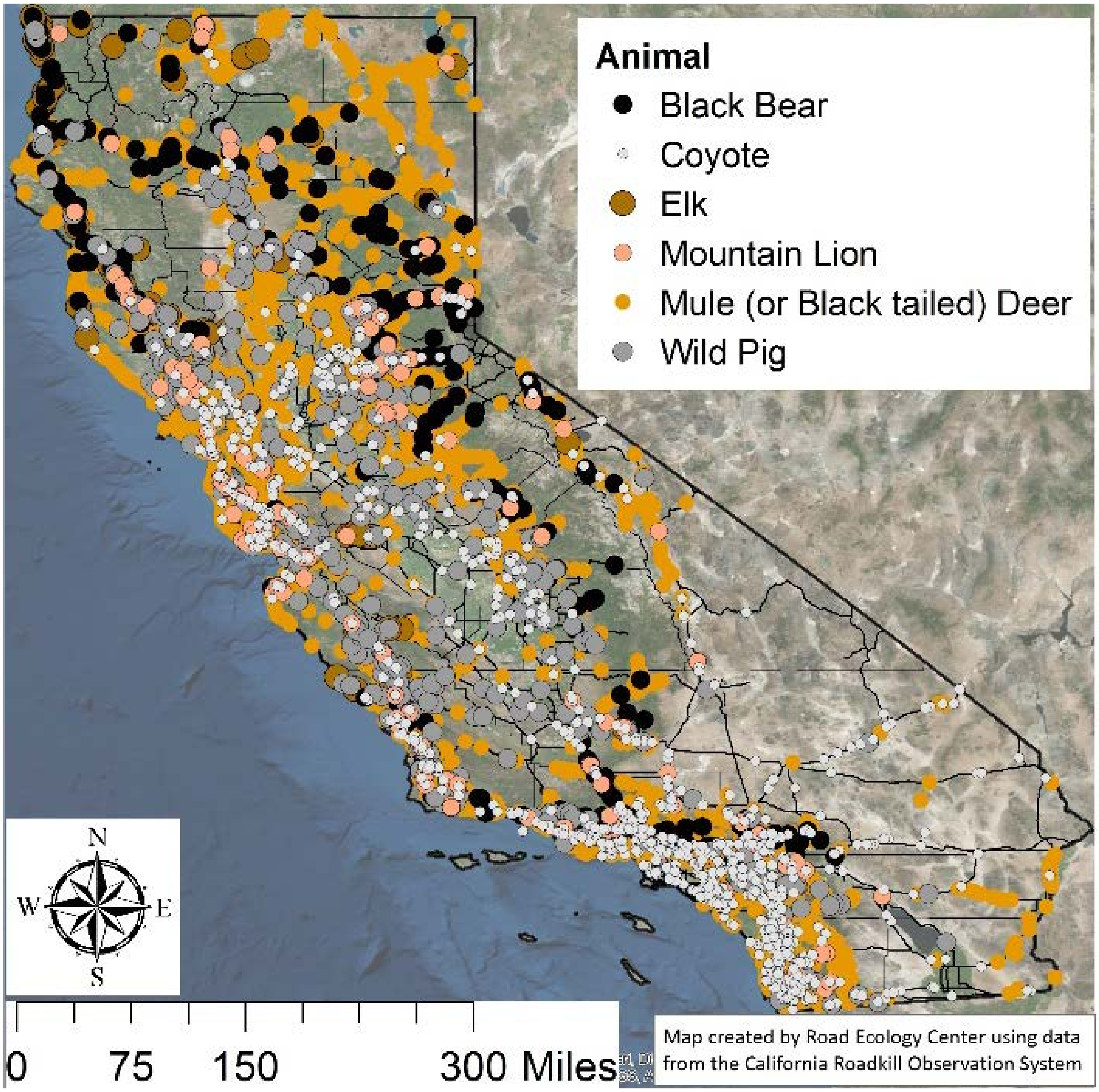
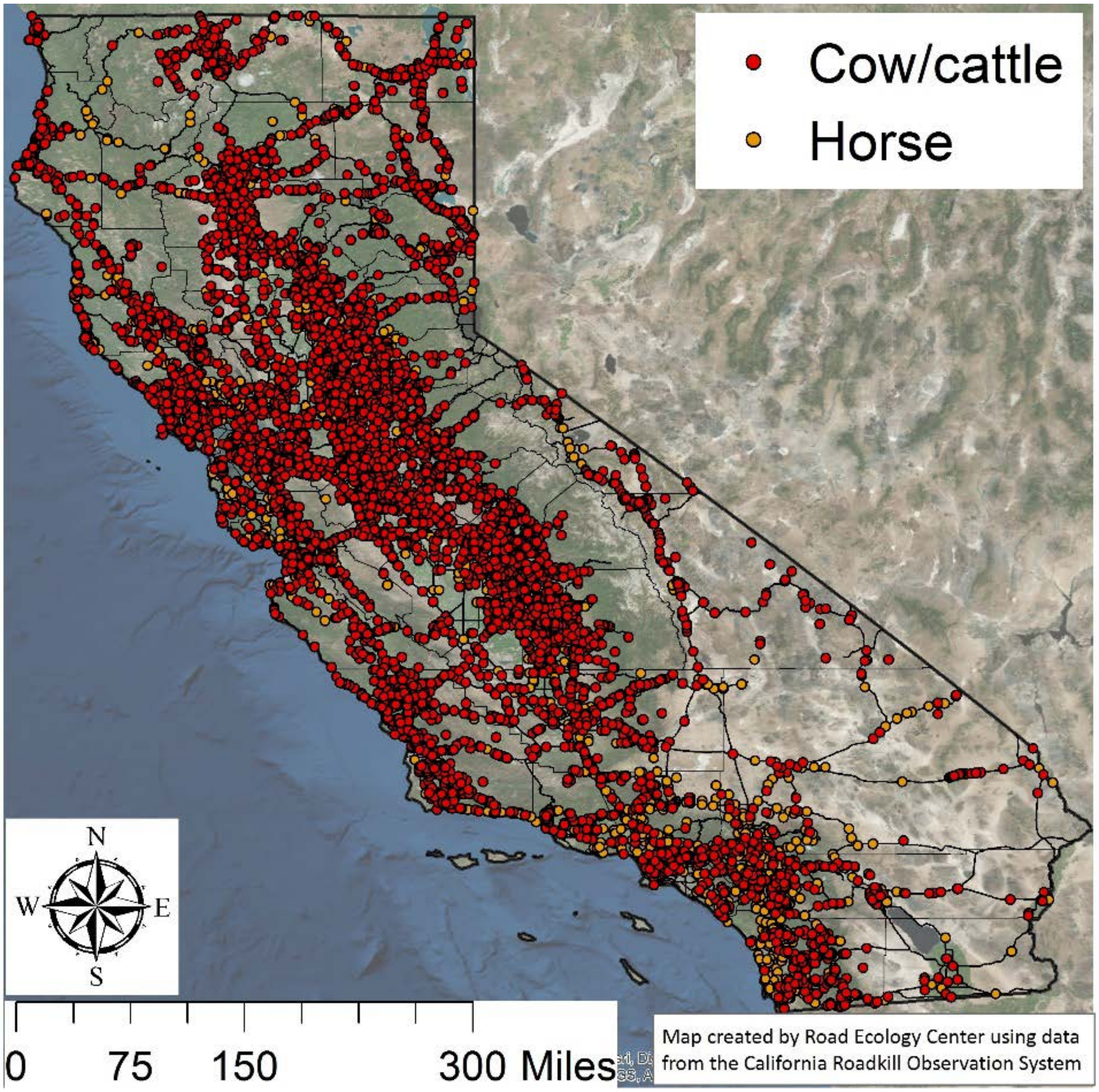


Figure 2. Wildlife-vehicle conflict (WVC) incidents on state highways (2015-2017)

For the first time, we also developed hotspot maps for animal-vehicle-conflict (AVC) involving domestic animals in free range areas, or that have escaped enclosures. Cattle, horse, sheep, pigs and goats can all become involved in conflict incidents with traffic. Because some of these animals can be quite large, larger than most wildlife (expect elk and some bears), collisions with them can be particularly severe for the drivers. We found that AVC occurs everywhere in California (Figure 3) and at fairly high rates.



Map created by Road Ecology Center using data from the California Roadkill Observation System

Figure 3. Animal-vehicle conflict involving domestic animals (cows/cattle and horses) for 2015 - 2017.

Statewide Wildlife-Vehicle Conflict Hotspots

Although WVC occur everywhere in California, the highest densities were reported in the San Francisco Bay Area (Caltrans District 4), Sierra Nevada Foothills (Caltrans Districts 3 & 10), North Coast (Caltrans District 1), and parts of the Central/South Coast (Caltrans Districts 5, 7, 11 & 12). These high-density areas are most likely where traffic volumes and wildlife populations are greatest, leading to more conflict. The map below shows the high-density clusters of collisions with large wildlife in California (Figure 4).

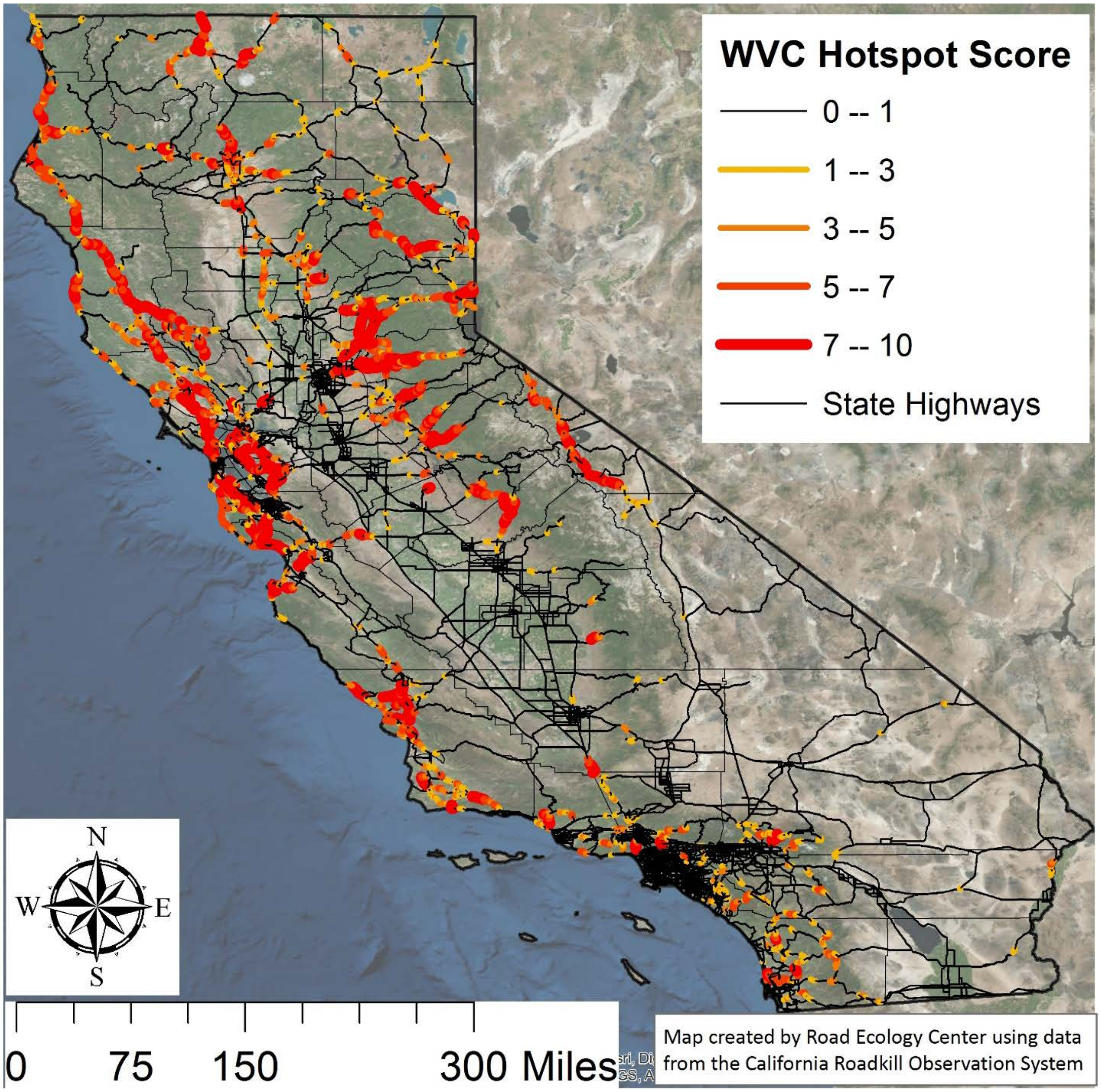
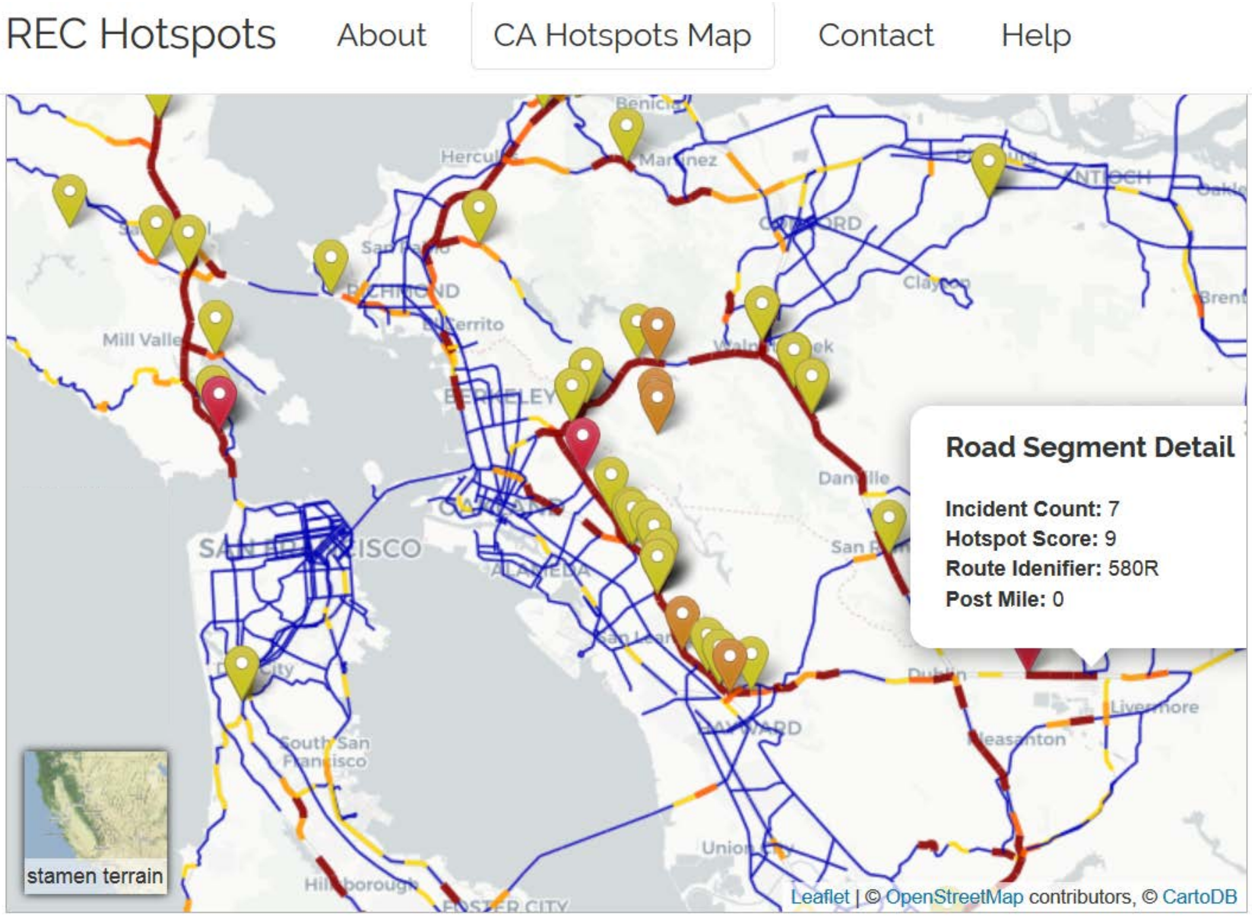


Figure 4. Statistically-significant, high-density WVC hotspots for 2015 to 2017. Hotspot score is a value that combines the total density of WVC incidents (#/mile) and the statistical significance of clusters of incidents. You can see these data here: https://roadecology.ucdavis.edu/hotspots.

Real-Time, Automated Web-Map of WVC

To better inform the public and transportation agencies about highway segments with greater risk of WVC, we developed an easy-to-use, online system that provides two important sources of information: 1) mapped hotspots using legacy data (2015 to end of 2017); and 2) locations of recent (<1 week & <24 hours) locations of conflict with mule deer and other large mammals (Figure 5). You can find the website here: https://roadecology.ucdavis.edu/hotspots.



Road Segment Detail

Incident Count: 7
Hotspot Score: 9
Route Idenifier: 580R
Post Mile: 0

Figure 5. Zoomed in view of central San Francisco Bay Area showing incident densities and recent WVC incidents. The information box appears when the user clicks on a highway segment. https://roadecology.ucdavis.ed/hotspots.

We also developed the web-system so that it could be a continuous source of information for driver-assist, autonomous-vehicle, and app-based programs. For example, this information could be continuously fed into an app to inform drivers of locations of recent and long-term conflict, to inform their driving practice. It could also be used by driver-assist and autonomous vehicle systems to prioritize driver-warning and changes in sensitivity to the potential presence of large animals in the roadway.

Consequences of Collisions to Drivers and Society

Records analyzed show some individual drivers involved in collisions with animals, or who drive by injured animals and report them, experience emotional trauma and if the animal is larger, also face damage to their vehicle and injury (or even death) to themselves. Drivers may either collide with the animal, or swerve to avoid the animal and become involved in a collision with another vehicle or object (Table 1). We estimated the total cost of all WVC incidents to society, using summaries of types of accident (e.g., property damage only, major injury), the loss of wildlife, and coefficients for each of these types of loss. Equivalent costs for accident types were obtained from the US Department of Transportation (USDOT, 2013) and a related project in South Dakota (Cramer et al., 2016). We only counted 1 fatality in data from CHP, but Caltrans reported 12 fatalities from collisions with wildlife for 2017, using data from CHP (http://www.dot.ca.gov/paffairs/pr/2018/prs/18pr072.html), so we used this number.

The rates of property damage, injury and death reported here are probably underestimates and may be superseded by more detailed information from other sources. For example, State Farm Insurance Co. estimates that there were >23,000 claims/year for collisions with deer in 2015- 2016 (https://newsroom.statefarm.com/download/234883/allstates2015-16deerstats-finalpdf.pdf), whereas our calculations are based on >6,600 reported collisions during this time period. If these additional 16,000 collisions resulted in the same average property-damage-only cost as used below (USDOT, 2013), there would be an additional >$277 million cost to society (16,000 times $17,343/crash), resulting in a total estimated cost from WVC of ~$584 million/year.

From 2016 to 2017, we found an increase of ~11% in cost to society from WVC, which was 20% higher than the year before. This does not reflect a change in how the calculation was conducted, but instead an increase in the number of fatal collisions.

Table 1. Impact to drivers and estimated cost to society of reported collisions with animals on California highways and certain major roads. Equivalent costs for accident types were obtained from the US Department of Transportation (2013).

Type of Accident	**Coefficient (cost as $/event)**	**Number (2017)**	**Cost (2017)**
Lost animal value (all animals)*			$37,377,000
Collision/Swerve (property damage)	$17,343	6,411	$111,185,973
Injury (minor)	$105,228	224	$23,665,146
Injury (major)	$506,217	44	$22,327,207
Fatality	$9,395,247	12	$112,742,964
Total			**$307,298,290**

* This value includes both reported and estimated un-reported carcasses. Others have reported under-reporting rates for carcasses from collisions of 5-10 fold (e.g., Olson et al., 2014).

Consequences of Collisions to Large Mammals, Animal Populations & Individual Animals

The majority of reported traffic incidents involving an animal (Figure 2) were with Mule deer (*Odocoileus hemionus*, 88%, Table 2), though at least 5 other mammals were also reported. In addition, these are just species and number of animals that were included in a CHP incident report. Others have reported under-reporting rates of collisions with ungulates (e.g., deer) of 5 to 10 fold (Donaldson and Lafon, 2008; Olson et al., 2014). This suggests that as many as 25,000 to 50,000 mule deer were killed during collisions in 2015 and an unknown number of other species. This is supported by the State Farm Insurance Co estimate of >23,000 claims/year for collisions with deer in California (https://newsroom.statefarm.com/download/234883/allstates2015-16deerstats-finalpdf.pdf), where collisions are likely to occur more often than claims.

One important observation was that almost twice as many black bears were reported involved in accidents in 2017 (170 animals) than in 2016 (89 animals), or 2015 (83 animals). In addition, there were more collisions with mountain lions in 2017 (64 animals) than in 2016 (44 animals), or 2015 (38 animals). It's not obvious why this occurred, but it is a disturbing trend for both wildlife and drivers

Table 2. The types and number of each type of wildlife involved in traffic incidents reported to CHP in 2016.

Wildlife type	**Number**	**% of Total**
Mule deer	5,862	88%
Coyote	353	5%
Black bear	165	2%
Wild Pig	145	<1%
Mountain lion	64	<1%
Elk	40	<1%

For people who have collided with an animal, some will have observed that the animal does not always die immediately. We found that 23% (n=1,495) of animals involved in incidents were reported as injured by responding law enforcement (Table 3). There were an additional 32% (n=2,119) with an unknown fate after being involved in a traffic incident. The rate of "unknown fate" for animals involved in a collision was much greater for elk, black bear and wild pig than mule deer, with the majority of these species having an unknown fate after collision. Only 149 animals were reported as dispatched by responding law enforcement officers, meaning that the remaining injured and some portion of the "unknown fate" animals stayed injured following the collision. This may still be an under-estimate of the total as there has been shown to be chronic under-reporting of collisions with ungulates, such as deer, in the US (Donaldson and Lafon, 2008; Olson et al., 2014).

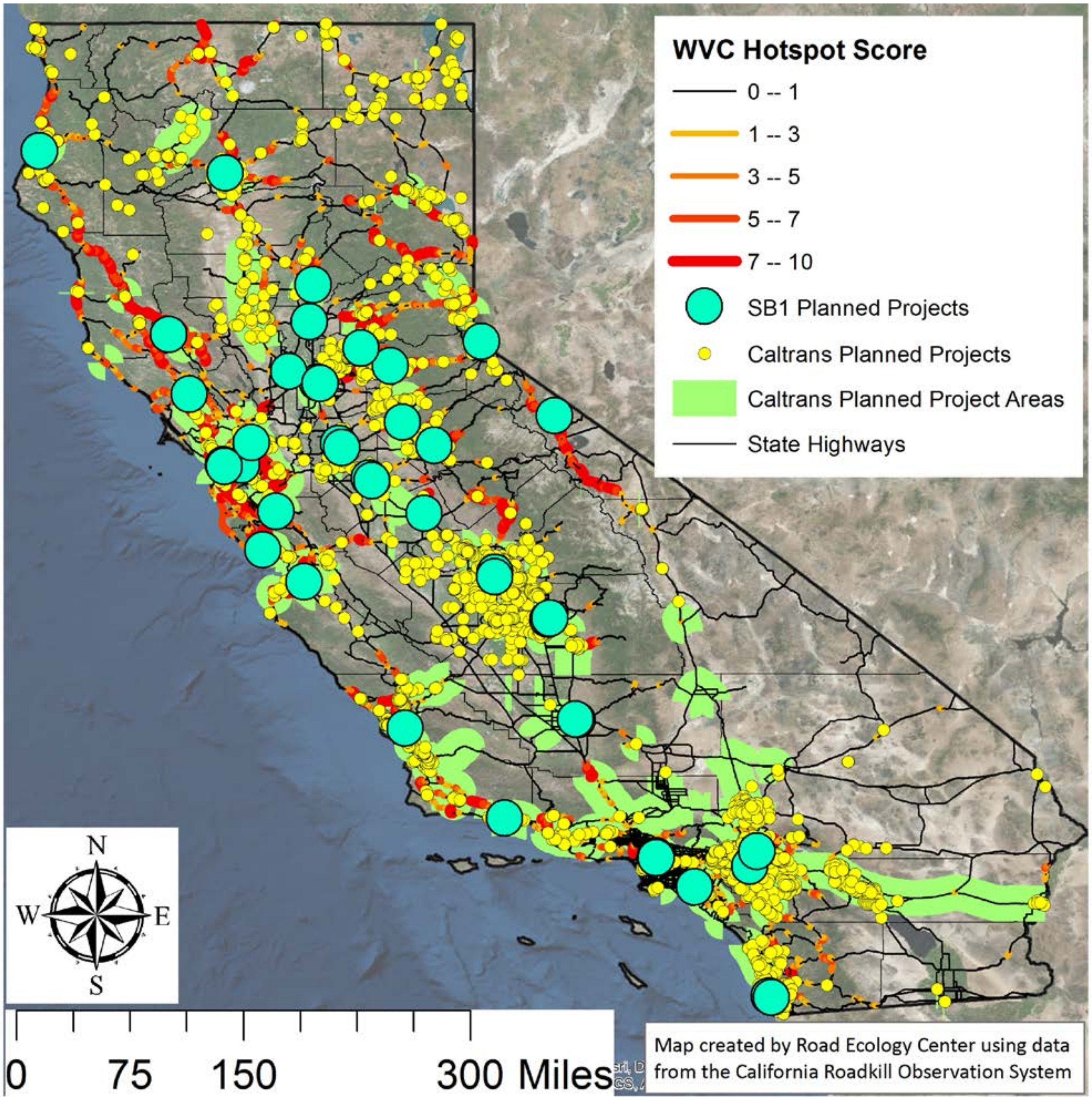
Table 3. Animal outcomes following collisions with vehicles in 2017.

Animal Outcome	**#**	**%**
Unknown fate	2,119	32%
Alive / No Injury	597	9%
Injury	1,495	23%
Fatality, result of collision	2,841	43%
Fatality, result of dispatch	149	2%
Total	6,604	

In last year's report, we suggested that injuring animals in this manner could be considered cruelty. Although this may still be true, it makes sense to consider what solutions are available to reduce the unnecessary suffering of animals injured during collisions. A possible solution to this problem would be for the state to create a hotline where drivers can report an injured animal for potential rehabilitation, or in extreme cases, dispatch by CHP. Other countries (e.g., Germany, Sweden) have systems like this in place that could readily be adopted.

Regional/Local Focus

The need for projects that reduce the risk to driver safety and lives, property damage, and impacts to wildlife is critical. Building these projects will require a combination of Caltrans, county, regional, and legislative action and funding. This risk is greatest when there are more drivers driving fast through or near wildlife habitat, such as the San Francisco peninsula, the Sierra Nevada foothills and portions of Southern California (see following pages). The map below (Figure 6) shows the location of planned, state-funded projects in California, which are potential locations for wildlife-vehicle collision mitigation. Unfortunately, there is not very good overlap between WVC hotspots and planned projects, including those planned under the Senate Bill 1 (SB1) fuel-tax funding source. This may not be surprising as neither the California Transportation Plan, nor SB1 mention widespread, adequate mitigation for this risk to driver safety and wildlife well-being. However, it is a problem that can be solved by spending SB 1 and other state funds on wildlife-crossing projects. There is an immediate and urgent need for leadership on this issue in California and widespread construction of wildlife crossings solutions to reduce harm to drivers and wildlife. We suggest an expenditure rate of "1% for wildlife", which equates to ~$500 million from transportation funds per year, coincidentally similar to the estimated cost per year of WVC.

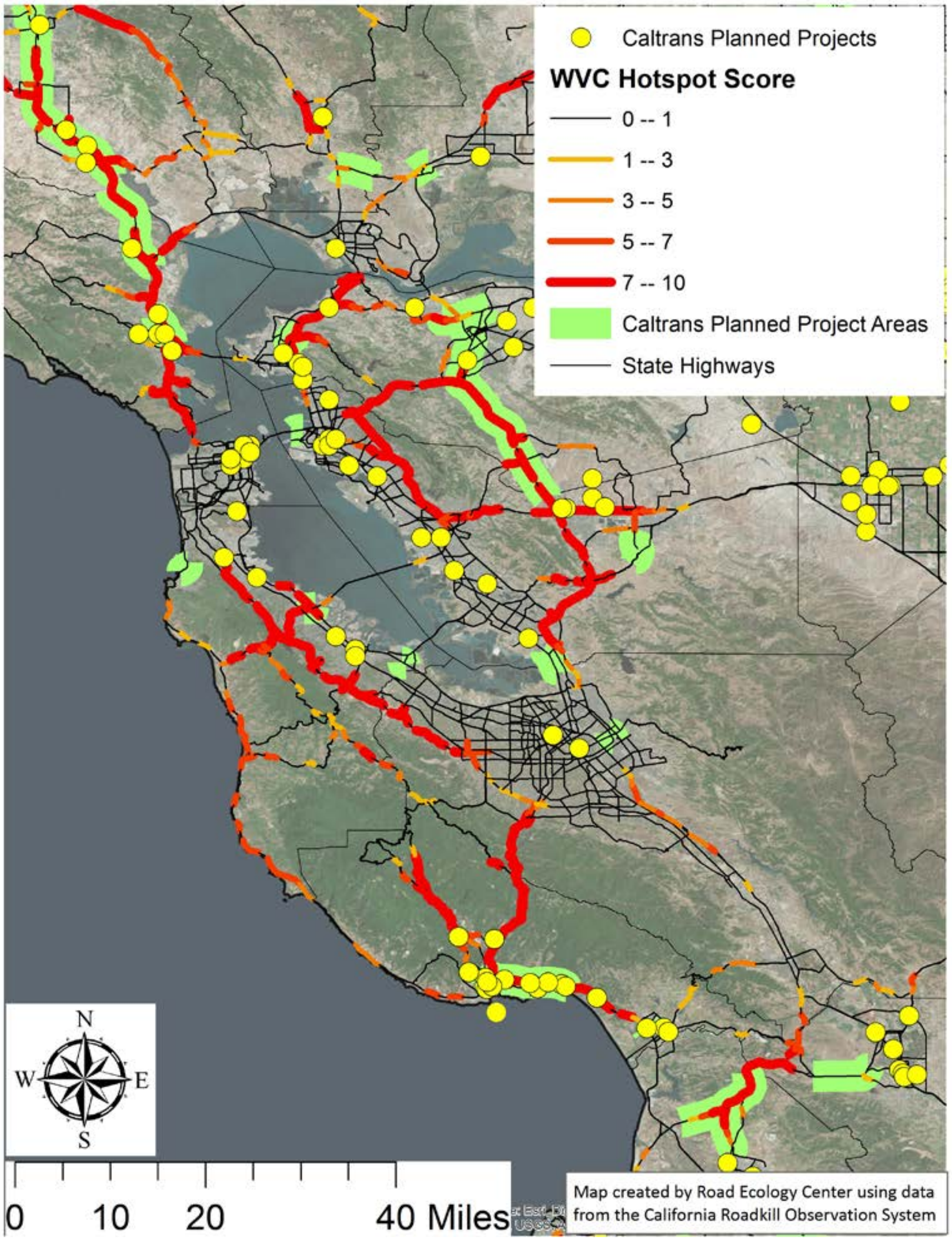


Map created by Road Ecology Center using data from the California Roadkill Observation System

Figure 6. Locations of WVC hotspots and planned projects under the State Transportation Improvement Program (STIP) and Senate Bill 1, fuel-tax funding.

San Francisco Bay Area, Regional Highway Hotspots

This map shows the hotspots of WVC incidents on select highways in the San Francisco Bay region (Figure 7). There are segments of highways that have high enough rates of WVC that if safety projects, such as fencing and wildlife crossings, were undertaken, they would pay for themselves through reduced WVC. This is especially true for I-280, the fencing of which would pay for itself in less than 1 year due to reduced WVC. Many major WVC hotspot areas have no planned highway projects, but projects should be planned to reduce risk and harm.

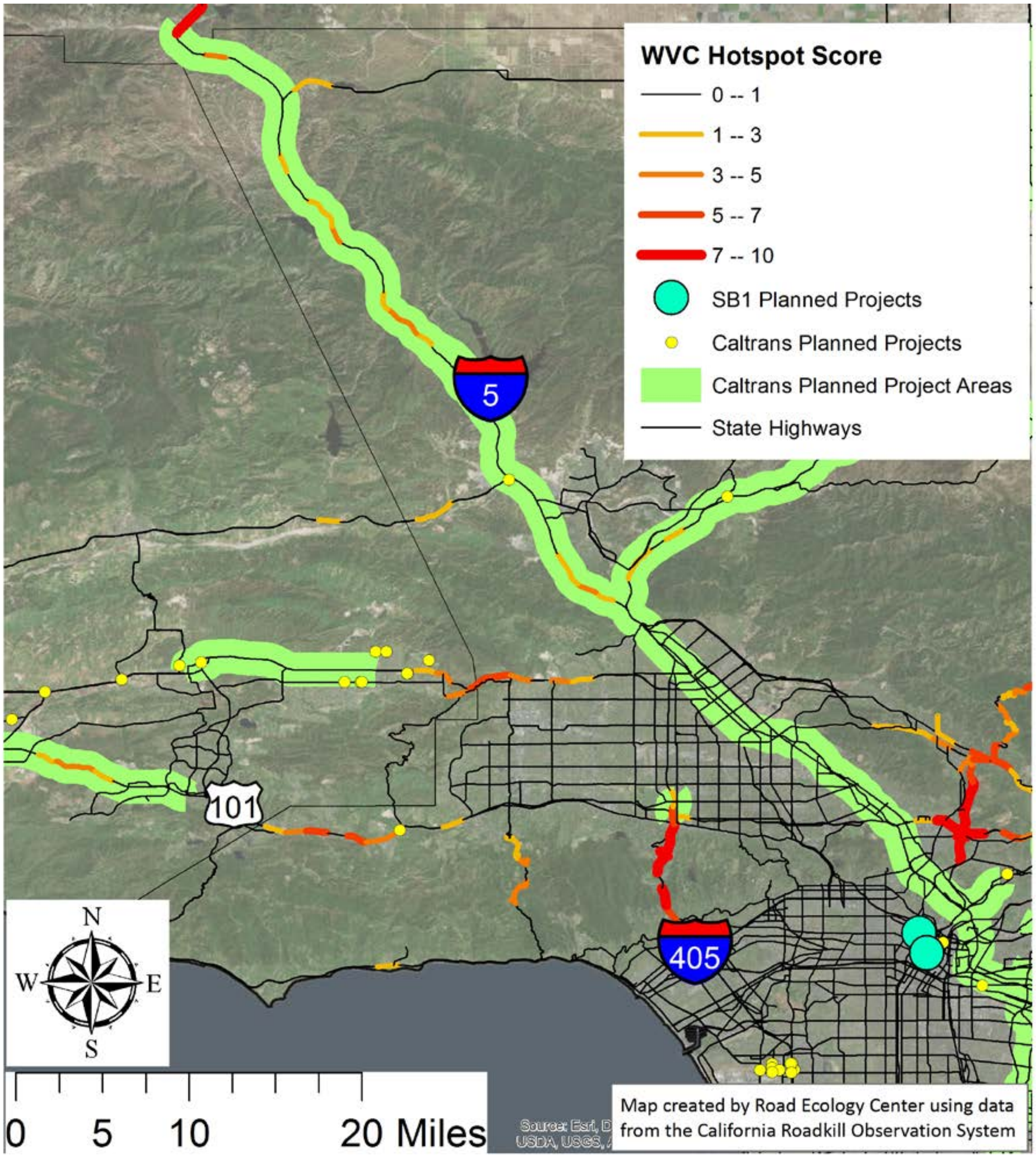


Map created by Road Ecology Center using data from the California Roadkill Observation System

Figure 7. Overlap of WVC hotspot areas with state-planned/funded highway projects in the San Francisco Bay Area.

Southern California, Regional Highway Hotspots

This map shows the clustering of WVC incidents on select highways in the northern Los Angeles basin and mountains (Figure 8). There are segments of highways that have high enough rates of WVC that mean if safety projects, such as fencing and wildlife crossings, were undertaken, they would pay for themselves through reduced WVC. There are several planned state-funded projects that could be used to build wildlife-crossing mitigation. There are also major hotspot areas with no planned highway projects, for which projects should be planned.

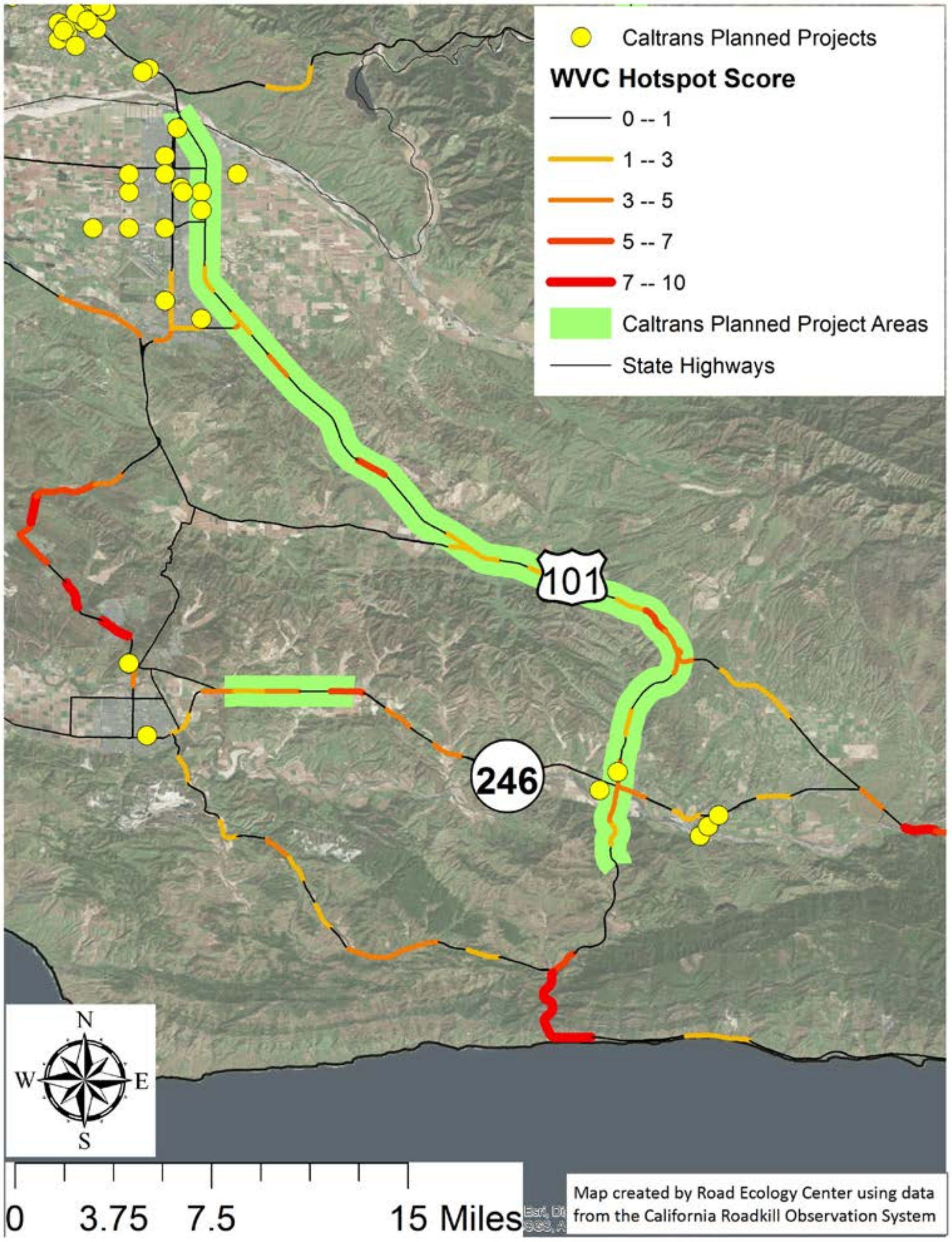


Map created by Road Ecology Center using data from the California Roadkill Observation System

Figure 8. Overlap of WVC hotspot areas with state-planned/funded highway projects in the Southern California mountains north/west of Los Angeles.

Central California, Regional Highway Hotspots

This map shows the clustering of WVC traffic incidents on select highways in central-coastal California (Figure 9). There are segments of highways that have high enough rates of WVC that if safety projects, such as fencing and wildlife crossings, were undertaken, they would pay for themselves through reduced WVC.

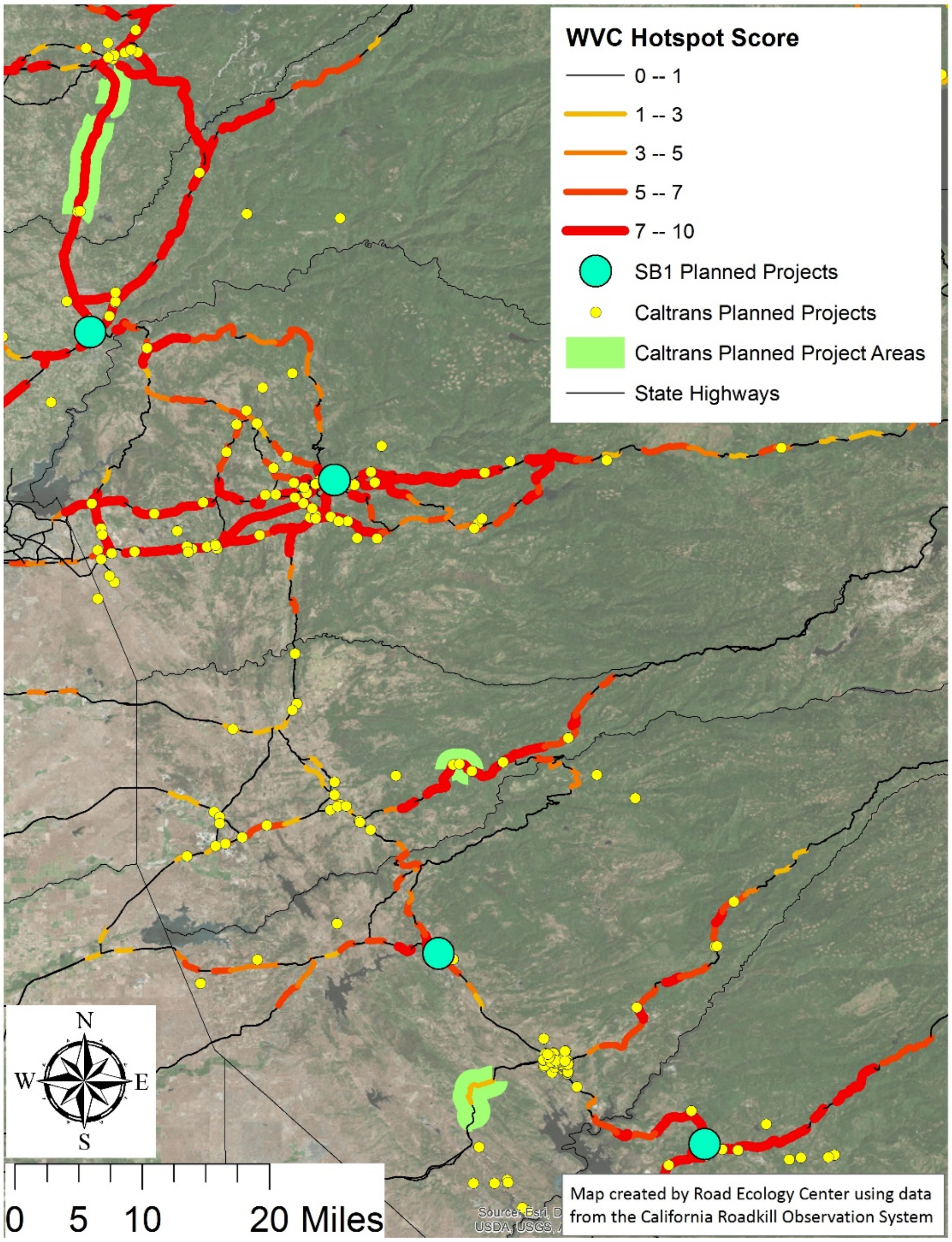


Map created by Road Ecology Center using data from the California Roadkill Observation System

Figure 9. Overlap of WVC hotspot areas with state-planned/funded highway projects in the Central California coast near Lompoc.

Sierra Nevada Foothills, Regional Highway Hotspots

This map shows the clustering of WVC incidents on select highways in the Sierra Nevada foothills (Figure 10). There are segments of highways that have high enough rates of WVC that mean if safety projects, such as fencing and wildlife crossings, were undertaken, they would pay for themselves through reduced WVC. There are several planned SB1-funded projects that could be used to build wildlife-crossing mitigation. There are also major hotspot areas with no planned highway projects, for which projects should be planned.



Map created by Road Ecology Center using data from the California Roadkill Observation System

Source: Esri, D USDA, USGS,

Figure 10. Overlap of WVC hotspot areas with state-planned/funded highway projects in the Sierra Nevada foothills east of Sacramento.

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Appendix 1: (More) Detailed Methods

Data Sources

State highway network (SHN) and post-mile (PM) spatial datasets were obtained from Caltrans (http://www.dot.ca.gov/hq/tsip/gis/datalibrary/index.php#Highway). All traffic incident data from California Highway Patrol (CHP) resources, beginning in 2/2017, were collected by the UC Davis Road Ecology Center's "California Highways Incident Processing System" (CHIPS) and ingested into a database. This database was then queried for incidents involving animals to create a dataset of Animal-Vehicle Conflict (AVC). The CHIPS AVC data includes collisions between vehicles and wildlife/domestic animals, carcasses found on highways, traffic hazards caused by animals, and other types of traffic incidents involving animals.

Each CHIPS data point contains several fields relating to the incident it represents. These fields include latitude, longitude, street or intersection name, animal species, and any details the CHP officer noted regarding the incident. Many points have multiple entries in the details field, meaning CHP documented updates to the incident as it progressed. These descriptions provide a thorough narrative of the incident, as well as details on the time that events occurred through the eyes of a CHP officer. Other fields in the AVC dataset are manually entered by the Road Ecology Center if they are included in the descriptions. Attributes include data like vehicle damage, driver and animal outcomes, and type of incident (e.g., swerve vs. collision).

CHIPS data represents incidents on California's state, interstate, and federal highways. CHP does respond and document incidents on some unincorporated roads near highways, but incidents more than 50 meters from a highway were excluded from this study.

It is important to note that CHIPS AVC data are a subset of reported incidents on California highways. Unreported incidents and incidents on roads falling outside of the jurisdictions of CHP are not included. CHP has jurisdiction on all federal, state, and interstate highways and public roads in certain unincorporated areas. Therefore, CHIPS incidents are not a record of all AVC in California, but events which induce a documented report within CHP jurisdiction.

Of the AVC incidents, ~90% of the incidents involved mule deer. It can be inferred that animals large enough to cause damage to a vehicle are more likely to be reported to CHP. A minimal number of incidents involve small animals, such as pigeons, geese, and dogs. These are included in the analysis dataset, but do not represent the entirety of incidents with those smaller animals. Thus, this analysis does not represent AVC with smaller species, since those incidents are unlikely to be reported.

Assuming CHP consistently and accurately documents incidents across the state highway network, CHIPS data provides a spatially unbiased dataset of AVC involving large animals on California highways.

Geoprocessing

The datasets from the previous section were processed using the programming language R and ESRI ArcMap 10.6. The following geoprocessing steps were performed to create the automated hotspot analysis for AVC.

Network Segmentation

The basis for the AVC network analysis is the highway network. In order to create a uniform unit for analysis, one-mile segments were created for highway networks. The Caltrans SHN was used for the AVC analysis of California. The highway lines were split at each one-mile PM. This created a fairly uniform set of segments, split at well-known locations.

Assigning Incidents to Segments

A custom R script was written to assign AVC incident points to spatially corresponding road segments. The R script uses the snapPointsToLines function in the maptools library. Points >50 meters from any segment were filtered out. This approach did not attribute incidents to incorrect road segments. The number of AVC incidents for each segment was summed in an attribute field to the segment, which is the metric of primary importance in the WVC analysis. A maximum distance of 50 meters was chosen when snapping incident points to road segments. Since CHP often records data on road shoulders, and the highway network is often on the centerline of roads, or between separated highway lanes, and GPS receivers have an accuracy radius, point locations are usually a short distance away from network lines. However, incorporating points further than necessary would have included WVC points on roads not in the analysis, inaccurately inflating density distribution.

Clustering Statistics – Hotspot Score

To provide a different view of the spatial distribution of AVC along the network, the Getis0Ord Gi* statistic was used to statistically analyze clusters and to contribute to a hotspot score for each one-mile road segment. An R script ran a local Getis-Ord calculation for each segment on the network, analyzing the number of incidents snapped to each segment. The default neighbor radius is one mile (1609 meters), and a binary weighted matrix including the value of the segment The script adds a Gi* z-score value to each segment, denoting if the segment is in a relative “hotspot” or “coldspot”.

The Gi* statistic is well-suited to identify hot and cold locations in density distribution, the resulting z-score is not clearly understood by all audiences. Moreover, some additional nuances of WVC distribution should be incorporated into an easily shared “hotspot score”.

Using the Gi* value, a “hotspot score” was created to more effectively communicate the results. First, segments with a) zero incident density or b) a negative Gi* value are assigned a hotspot score of zero. This avoids over-smoothing the score, to reveal highway segments with no incidents in a region of high incidents. Then, a percentile of each Gi* value within the distribution of remaining non-zero segments is calculated. Finally, an integer value from 1-10 is given to each segment by rounding up the percentiles. The hotspot score is a means of synthesizing incident density and spatial clustering, but presenting it in a way that is easily understood by all audiences. The process can be implemented on any network, and will categorize network segments into 10 equally sized categories, where each segment with a score greater than zero has incident densities and positive Gi* values.