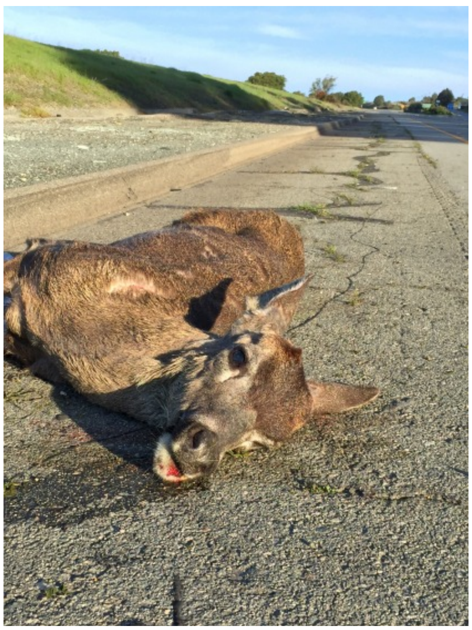
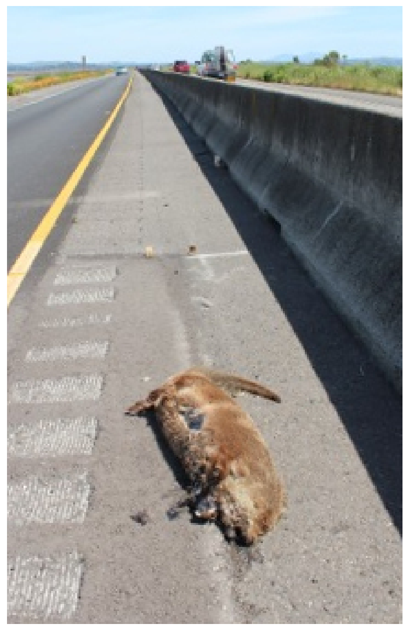
2017

Road Ecology Center, UC Davis

Fraser Shilling, Ph.D., Co-Director
David Waetjen, Ph.D., Programmer
Kathryn Harrold, Consultant





Impact of Wildlife-Vehicle Conflict on California Drivers and Animals

Using observations of reported traffic incidents and carcasses the Road Ecology Center estimates the total annual cost of wildlife-vehicle conflict (WVC) in California to be at least $276 million, up 20% from the year before. This report includes maps of WVC hotspots, discusses impacts to wildlife and people from WVC, and ranks highways in each Caltrans District for financial cost of WVC (spoiler, I-280 in District 4 is the costliest). Projects to reduce WVC can be the most effective of any safety project, with effectiveness often >90%. In addition, only 1-2% of California's transportation budget, including the new Senate Bill 1 funds, would be required to carry out these safety projects.

This report provides an overview of wildlife-vehicle conflict (WVC) hotspots on California highways in 2015 and 2016, 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). Because Caltrans does not systematically record where they pick up the tens of thousands of wildlife carcasses per year they dispose of from state highways, these data are not included. Analytical details are available from Fraser Shilling (fmshilling@ucdavis.edu) upon request.

Photo acknowledgements

Mule deer – Kathryn Harrold
Otter – Fraser Shilling

Data collection acknowledgements

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 collected >53,000 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 is now 9 years old, 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 also released a new journal article on CROS, published in the peer-reviewed journal Frontiers of Ecology and Evolution, covering the technical details of the project, including the accuracy of volunteer observations. The paper also covers details of our other project in Maine, called the Maine Audubon Wildlife Road Watch (http://wildlifecrossing.net/maine). Finally, we have partnered with other similar systems around the world in the Globalroadkill.net project (http://globalroadkill.net).

Citation: 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

Contents

The Authors

Fraser Shilling is the Co-Director of the UC Davis Road Ecology Center (http://roadecology.ucdavis.edu). He actively investigates the impacts of transportation systems on natural systems and human communities. He received his PhD in 1991 from the University of Southern California in the Division of Biological Sciences. Dr. Shilling directs the California Roadkill Observation System, the largest system in the world for volunteer observations of roadkill. David Waetjen is lead programmer and web guru for the Road Ecology Center. He received his PhD from UC Davis (Geography) in 2011. He develops web-systems and spatial analyses for wildlife, water, and sustainability applications. Kathryn Harrold is an independent wildlife consultant who is expert in how wildlife interact with roadways and how we can improve roads/highways to protect drivers and wildlife from conflict.

Contact: Fraser Shilling, Co-Director, Road Ecology Center, UC Davis; fmshilling@ucdavis.edu, 530-752-7859; @roadecology

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

Top 5 Recommendations

1) Systematically collect data. The state data assembled here were not collected with the purpose of studying wildlife-vehicle conflict, the volunteer data were. California agencies should up their wildlife game and collect data about wildlife-vehicle conflict. This is especially true for Caltrans, which already collects and disposes of tens of thousands of wildlife carcasses annually, but does not record or report the data.

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 and their habitat. Highway projects that are likely to increase WVC can be approved and 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. We need ten times that rate in order to reduce risk to both drivers and wildlife.

4) Use our vast transportation resources to support this critical need. New funds from Senate Bill 1, $5.3 billion annually, along with existing transportation project funds mean that we could easily build 10 times as many large WVC reduction projects per year, but we choose not to.

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 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 <u>annual</u> cost to society from >7,400 WVC incidents in

California on state highways and a small proportion of major roads to be ~$276 million for 2016, which is a 20% increase over 2015. **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).** Allstate Insurance Co. estimates that California had >23,000 claims/year for collisions with wildlife in 2015-2016, which is >3 times the rate we describe here and if included, would result in a total cost to society of >$500 million/year. 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 life threatening 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. According to Caltrans and California Highway Patrol statistics, there are >7,000 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 second year analyzing CHIPs 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. 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 February 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. We separated the ~13,000 records of wildlife-vehicle collisions from the ~1.4 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 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 (Shilling and Waetjen, 2017). More than 53,000 WVC observations were contributed to the website by volunteers between August 2009 and the end of 2016 and by Caltrans Maintenance staff for the period 1987 to 2007. We selected recent observations of large-animal carcasses (last two years) and combined these observations with the CHP crash data.

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 spatial autocorrelation tests (Morans I, Getis-Ord, and KDE plus). 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).

Major Findings

Statewide Carcass Observations

The maps below show >53,000 observations of animal carcasses on local roads and state highways (Figure 1) and the density of carcasses across the state (Figure 2). 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 2016.

A) B)

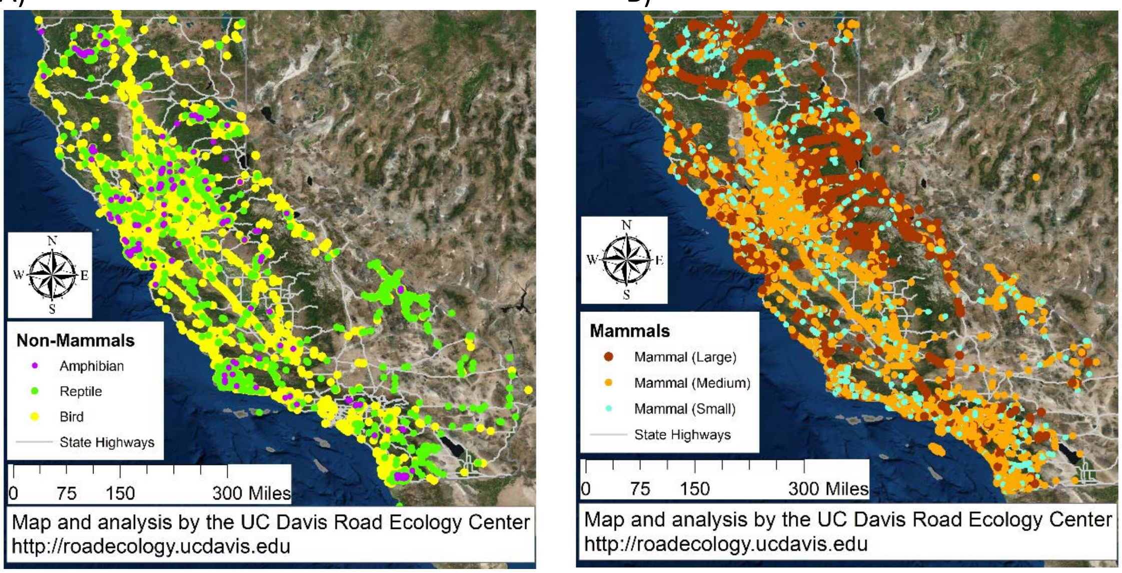


Figure 1. Carcass observations for (A) amphibians, reptiles, and birds; and (B) mammals of various sizes.

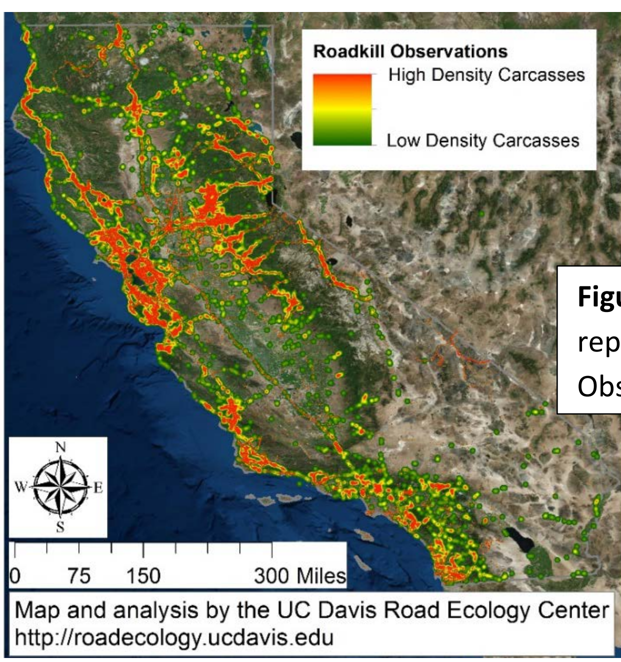


Figure 2. Density of roadkill carcasses reported to the California Roadkill Observation System.

Statewide Highway Traffic Incidents

There were at least 1.4 million traffic incidents (of all types) across California reported to the California Highway Patrol in 2015 and 2016 (Figure 3, All Traffic Incidents). Of these, about half were collisions and more than 13,000 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 3, Wildlife Vehicle Collisions). October was the most dangerous month for conflict, with about twice as many incidents as other months (inset graph). This may be because of increased movement related to mating season and seasonal migration.

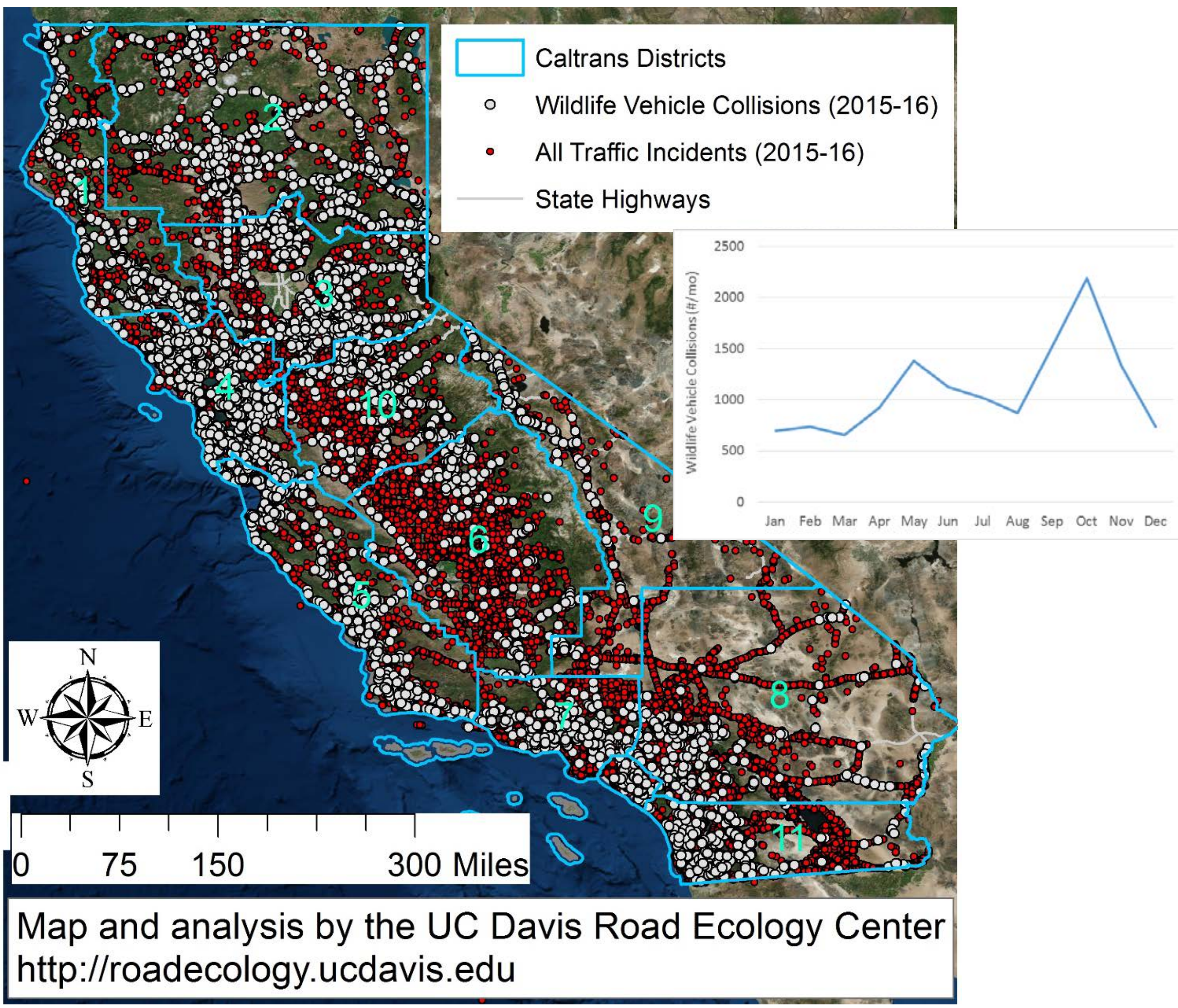


Figure 3. All traffic incidents (dark symbols) and those involving wildlife (white symbols) in the California Highways Incident Processing system (CHIPs) for 2015 and 2016. Caltrans districts are numbered and outlined in blue. Inset graph: number of WVC per month for 2015 - 2016.

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 density of collisions with large wildlife in California (Figure 4).

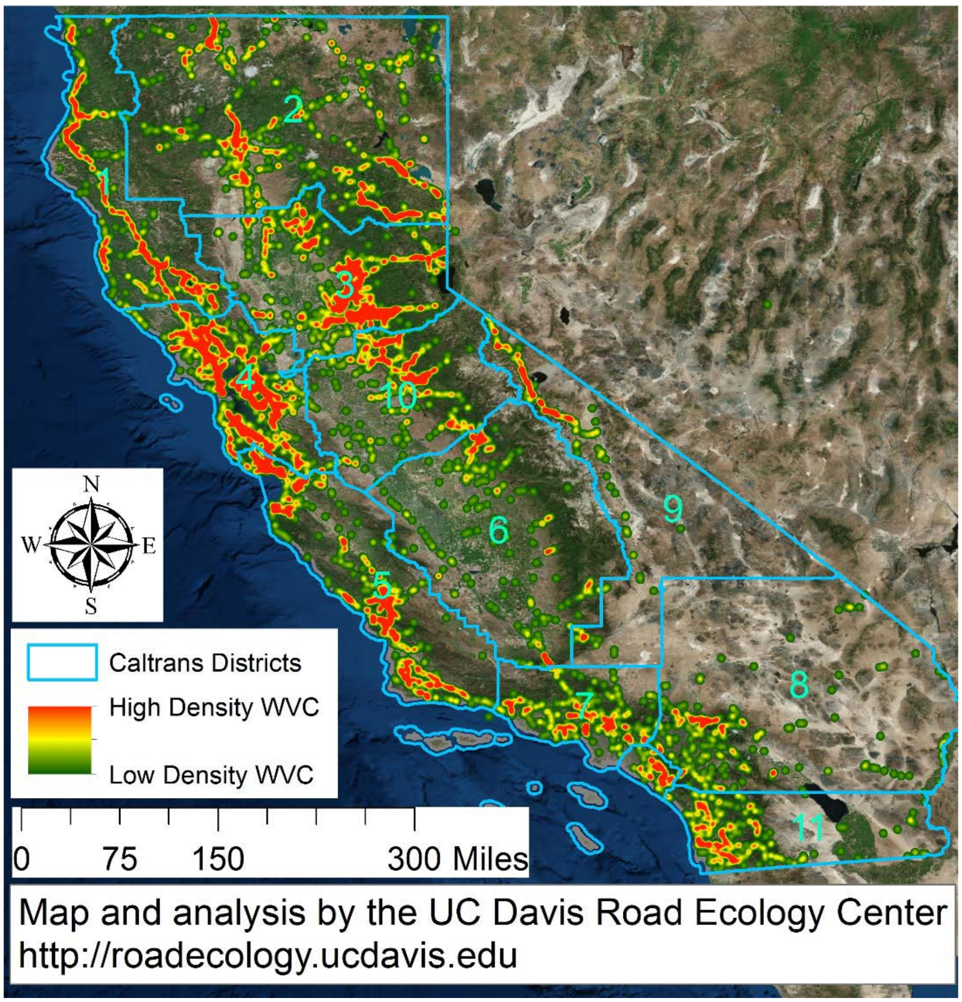


Figure 4. A) Density of all WVC for 2015 and 2016.

In order to inform statewide decision-making about resource-distribution to reduce WVC, we mapped the density of WVC across all highways/roadways (Figure 4). In order to inform decision-making about specific highways, we also mapped statistically-significant clusters of points along highways with the highest rates of WVC (Figure 5, below). For many highways, there are back-to-back clusters of WVC, resulting in entire stretches of highway being highlighted as a hotspot (e.g., highway 395 on the east-side of the Sierra Nevada).

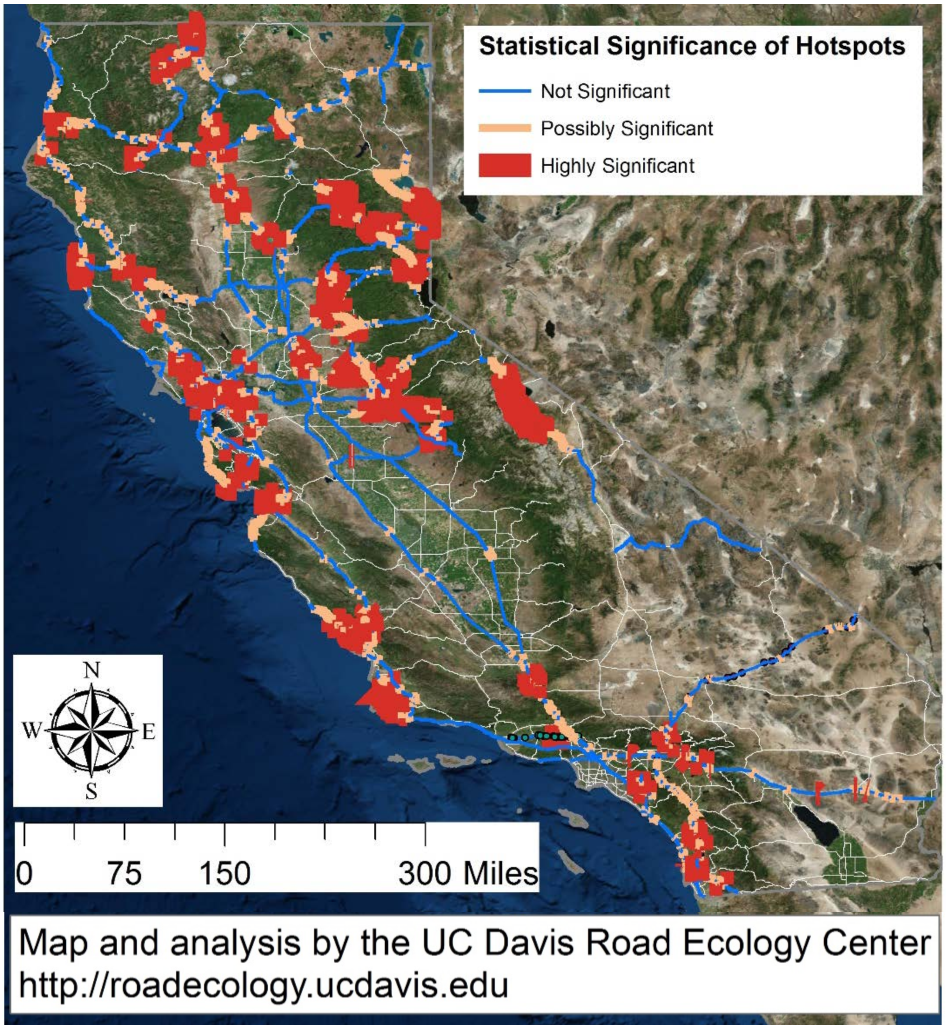


Figure 5. Statistically-significant hotspots for collisions of vehicles with large mammals on certain highways.

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). Because the number of fatalities may not be accurately reported in data obtained from state resources, we used an average value for California in 2015 (5.3/year, average 2005-2014) of the number of fatalities per year from collisions with wildlife, obtained from the Insurance Institute for Highway Safety (http://www.iihs.org/iihs/topics/t/roadway-and-environment/fatalityfacts/fixed-object-crashes, accessed 9/13/2016). In 2016, 5 fatalities were reported in crashes with wildlife.

The rates of property damage, injury and death reported here are probably underestimates and may be superseded by more detailed information from state sources. For example, Allstate Insurance Co. estimates that there were >23,000 claims/year for collisions with deer in 2015-2016, whereas our calculations are based on >7,000 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 >$312 million cost to society (16,000 times $17,343/crash), resulting in a total estimated cost to society from WVC of ~$588 million/year.

From 2015 to 2016, we found an increase of ~20% in cost to society from WVC. This does not reflect a change in how the calculation was conducted, but instead an increase in the number of collisions. For example, there was a 25% increase in injury accidents from 2015 to 2016.

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 (2015/2016)	Cost 2015	Cost 2016
Lost animal value (all animals)*			$36,165,000	$37,733,000
Collision/Swerve (property damage)	$17,343	5,368/7,479	$94,467,321	$130,055,157
Injury (minor)	$105,228	235/285	$24,771,329	$30,011,602
Injury (major)	$506,217	44/62	$22,067,897	$31,281,437
Fatality	$9,395,247	5.3*/5	$49,794,809	$46,976,235
Total			**$224,619,659**	**$276,057,431**

* 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).
** Average CA fatality rate from collisions with animals for 2005-2014

To aid Caltrans and county transportation agencies in mitigating costly WVC incidents, we mapped the cost per mile of WVC for select highways (Figure 6). To put the costs and corresponding colors into perspective, fencing of any highway segment in light orange to red would pay for itself within 1 to 4 years through reduced collisions. Fencing highway segments in yellow would pay for itself in 4 to 20 years. In both cases, the fencing would stretch from one logical end-point (e.g., bridge) to another, so actual costs would vary. Previous research has shown that fencing and crossing structures can reduce collisions >90% when fencing is maintained. In the Bay Area, long stretches of I-280, I-680, and US-101 could be fenced and significant cost-reductions (and reduced injury and death for people and animals) realized through reductions in WVC.

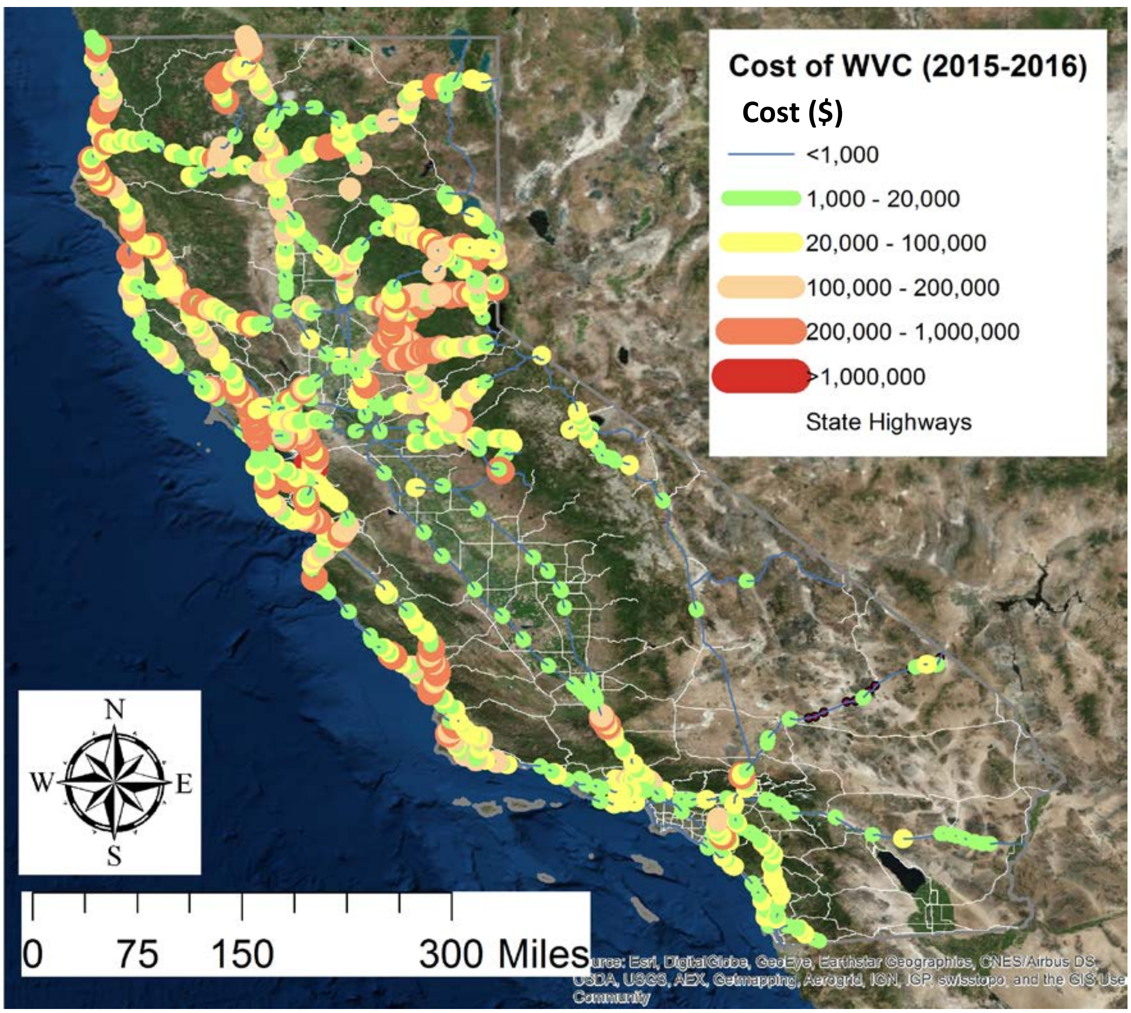


Figure 6. Cost of WVC per mile for select highways in California.

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

The majority of reported traffic incidents involving an animal (Figure 3) were with Mule deer (*Odocoileus hemionus*, 89%, 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 Allstate Insurance Co estimate of >23,000 claims/year for collisions with deer in California, where collisions are likely to occur more often than claims.

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	6,119	89%
Coyote	377	9%
Black bear	135	2%
Elk	44	<1%
Mountain lion	43	<1%
Wild pig	21	<1%

For people who have collided with an animal, some will have observed that the animal does not always die immediately. We found that 21% (n=1,431) of animals involved in incidents were reported as injured by responding law enforcement (Table 3). There were an additional 30% (n=2,048) with an unknown fate after being involved in a traffic incident. We have found previously that as many as 40% of all animals could have been injured during the traffic incident. Only 131 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 2016.

Animal Outcome	**#**	**%**
Unknown fate	2,048	30%
Alive / No Injury	500	7%
Injury	1,431	21%
Fatality, result of collision	2,618	39%
Fatality, result of dispatch	131	1.9%
Total	6,728	

These findings raise the question of whether these incidents where animals are injured in a collision are covered by California's statutory definition of animal cruelty (California Penal Code, Sec. 597) which defines cruelty as including where animals are "mutilated, or cruelly killed" or where any animal is subject to "needless suffering". Typically, wildlife are exempted from these statutes because they may be otherwise hunted and killed. However, the cruelty exemptions (Sec. 599c) cover permitted/licensed killing of game animals (e.g., for food) and not killing in general. Drivers are not being accused of being cruel, but it will help them as much as animals to do everything possible to prevent the collision and therefore stop the resulting cruelty.

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.

Where There is Smoke, There is Fire

One way to predict where WVC might occur in the future, and therefore prevent it, is to record collisions and the presence of dead animals. Another possibility is to investigate where live animals occur near highways, before they are hit. We compared the observations by CHP officers of live animals (primarily deer) with reports of dead animals and collisions of vehicles with animals. In many cases, if a live animal was reported present and adjacent to traffic lanes, collisions occurred later in the same area (Figure 7). This suggests that after a live animal is observed on the roadside, there is a risk that the animal may try to cross the road and become involved in a collision with a vehicle. This relationship seems weakest in rural areas (Figure 7A) and strongest near urban centers (Figure 7B,C).

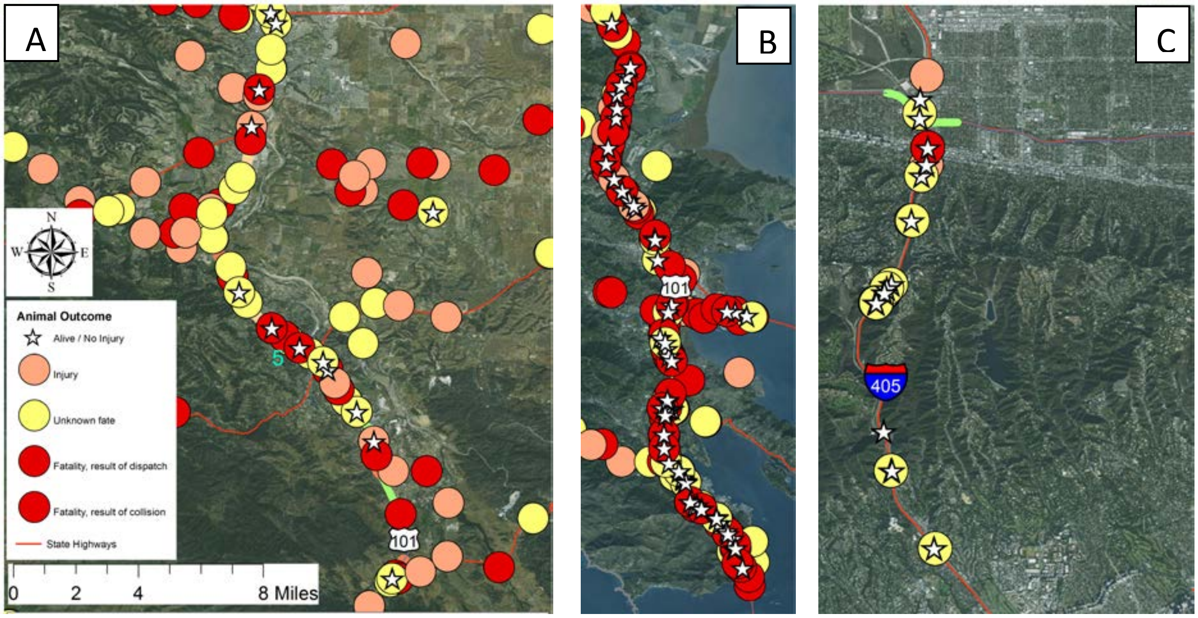


Figure 7. Comparison of observations of live (stars) and injured/dead (circles) animals on or adjacent to highways. A) US 101 north of San Luis Obispo. B) US 101 immediately north of Golden Gate Bridge (Marin County). C) I-405 south of Sherman Oaks in the Los Angeles area.

Regional 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. From this point of view, it is important to understand where these impacts and costs are greatest. In general, anywhere drivers and wildlife habitat are near each other, there is some risk of WVC. 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 the hills surrounding the Los Angeles basin. The map below shows the 15 California Senate districts where 90% of the cost and impact are located (Figure 8). Five of these districts have Republican senators and 10 have Democrat senators, suggesting that the problem and funding solutions are both bipartisan.

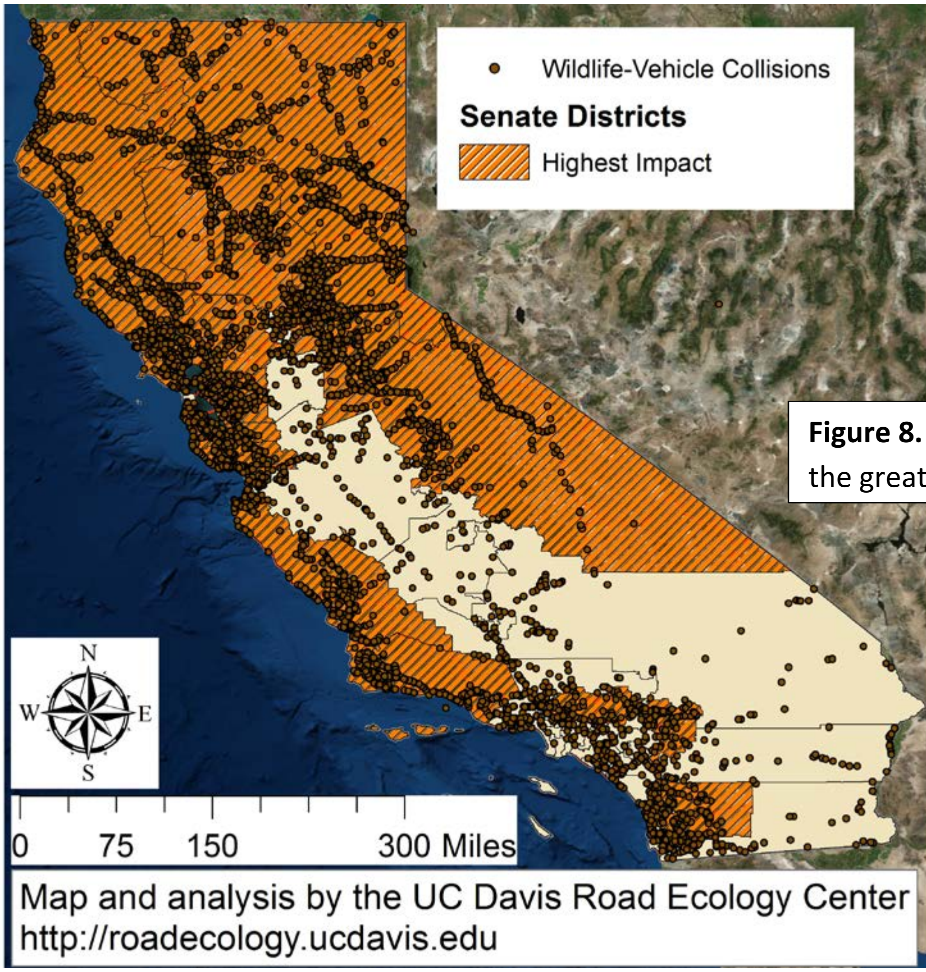


Figure 8. Senate Districts with the greatest impact from WVC.

The following sections highlight 3 regions in California, showing the top highway segments in each region for WVC and providing an estimate of how quickly projects designed to reduce WVC would pay for themselves.

San Francisco Bay Area, Regional Highway Hotspots

This map shows the cost and clustering of WVC traffic incidents on select highways in the San Francisco Bay region (Figure 9). There are segments of highways that have rates and costs of WVC that mean if safety projects, such as fencing and wildlife crossings, were undertaken, they would pay for themselves through reduced WVC (Table 4). This is especially true for I-280, the fencing of which would pay for itself in less than 1 year due to reduced WVC.

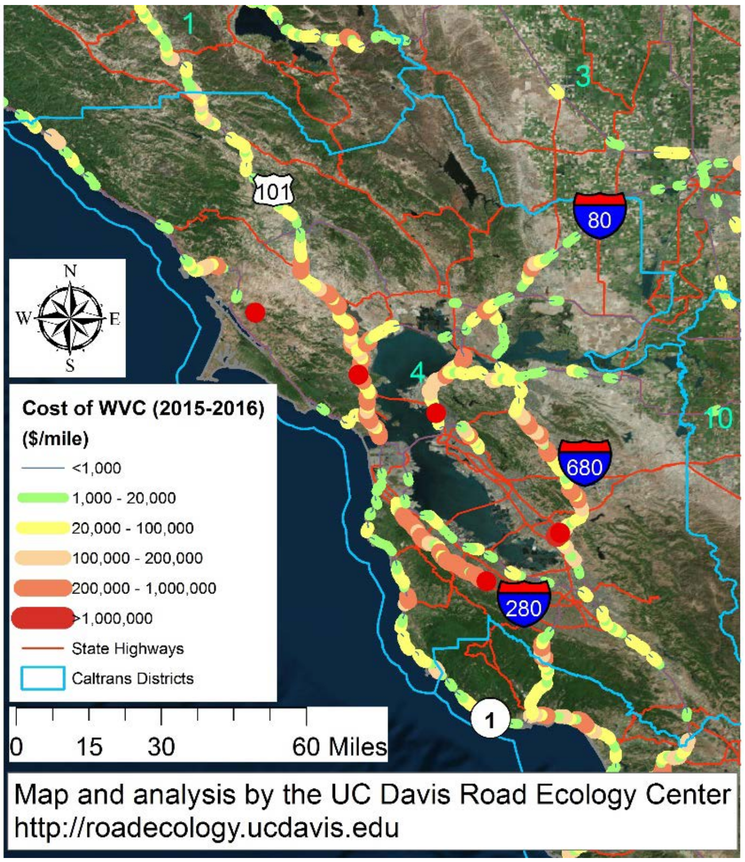


Figure 9. Cost ($/mile) of WVC for select highways in the San Francisco Bay Area/Caltrans District 4.

Table 4. Cost-effectivenenss of WVC mitigation action on Bay Area highways, fencing only. New crossing structures would cost an additional 2-10 million for most highways in list. Enhancing existing structures would cost less.

Highway	Injury/Property Damage (#)	Injury/Fatal (#)	Two-year cost ($)	Length (miles)	Cost/mile	Years to Pay Off (Fence)
I-280	386	26	$20,113,971	23	$874,520	0.5
SR101 (Marin Co)	225	11	$14,700,264	28	$525,009	0.8
SR13	81	4	$1,996,915	6.5	$307,218	1.3
SR24	114	4	$2,569,234	11	$233,567	1.7
I-680	221	6	$13,950,875	72	$193,762	2.1
SR9	119	7	$3,039,900	20	$151,995	2.6
SR17	62	2	$1,712,173	27	$63,414	6.3
I-80	129	5	$2,977,412	57	$52,235	7.7
I-580	55	4	$1,545,997	30	$51,533	7.8
SR1	142	6	$3,290,756	85	$38,715	10.3

Southern California, Regional Highway Hotspots

This map shows the cost and clustering of WVC traffic incidents on select highways in Southern California (Figure 10). There are segments of highways that have rates and costs of WVC that mean if safety projects, such as fencing and wildlife crossings, were undertaken, they would pay for themselves through reduced WVC (Table 5).

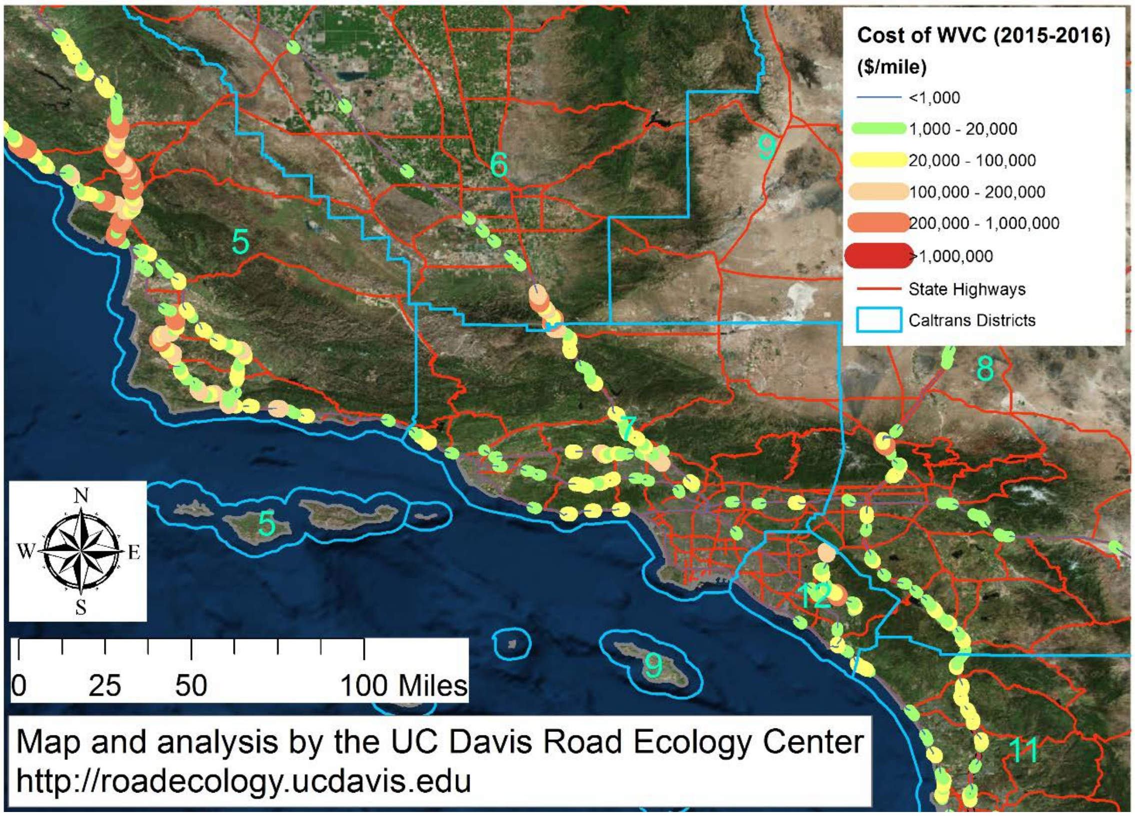


Figure 10. Cost ($/mile) of WVC for select highways in the Southern California region/Caltrans Districts 5, 6, 7, 8, 11 & 12.

Table 5. Cost-effectivenenss of WVC mitigation action on Bay Area highways, fencing only. New crossing structures would cost an additional 2-10 million for most highways in list. Enhancing existing structures would cost less.

Area/Highway	Injury/Property Damage (#)	Injury/Fatal (#)	Two-year cost ($)	Length (miles)	Cost/mile	Years to Pay Off (Fence)
SR2	33	2	$868,385	6	$144,731	2.8
US101	13	11	$3,581,108	26	$137,735	2.9
I-405	38	0	$659,034	8	$82,379	4.9
I-5	49	1	$997,840	15	$66,523	6.0
SR134	18	1	$460,207	7	$65,744	6.1
SR154	38	3	$1,103,133	19	$58,060	6.9
SR33	17	1	$442,864	8	$55,358	7.2
SR118	19	1	$417,402	8	$52,175	7.7
SR74	31	4	$1,129,765	23	$49,120	8.1
SR1	75	4	$1,892,857	47	$40,274	9.9

Sierra Nevada Foothills, Regional Highway Hotspots

This map shows the cost and clustering of WVC traffic incidents on select highways in the Sierra Nevada foothills (Figure 11). There are segments of highways that have rates and costs of WVC that mean if safety projects, such as fencing and wildlife crossings, were undertaken, they would pay for themselves through reduced WVC (Table 6).

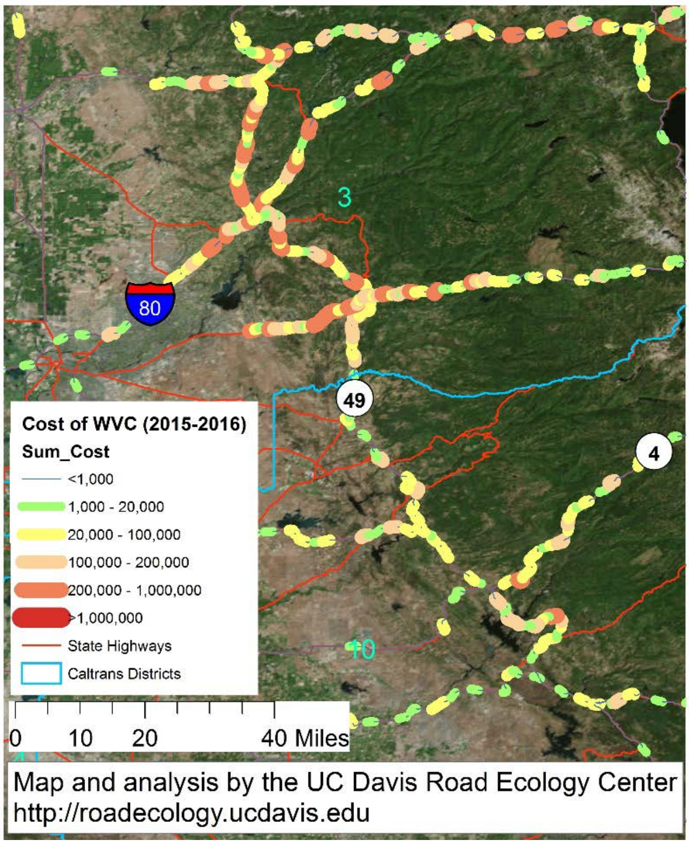


Figure 11. Cost ($/mile) of WVC for select highways in the Sierra Nevada foothills/Caltrans Districts 3 & 10.

Table 6. Cost-effectiveneness of WVC mitigation action on Sierra Nevada Foothill highways, fencing only. New crossing structures would cost an additional 0.5 to 1 million for most highways in list. Enhancing existing structures would cost less.

Highway	Injury/Property Damage (#)	Injury/Fatal (#)	Two-year cost ($)	Length (miles)	Cost/mile	Years to Pay Off (Fence)
SR174	75	5	$2,381,731	11	$216,521	1.8
SR50 (West)	245	15	$6,409,382	54	$118,692	3.4
SR108	107	3	$2,179,504	22	$99,068	4.0
I-80	154	12	$4,266,774	49	$87,077	4.6
SR44	67	4	$1,693,965	25	$67,759	5.9
SR49	310	22	$8,452,612	133	$63,553	6.3
SR20	82	8	$2,486,094	45	$55,247	7.2
SR88	49	3	$1,380,621	25	$55,225	7.2
SR41	74	3	$1,607,185	35	$45,920	8.7
SR4	54	3	$1,380,621	38	$36,332	11.0

Citations

Cramer, P., J. Kintsch, K. Gunson, F. Shilling, M. Kenner, and C. Chapman. 2016. Reducing Wildlife-Vehicle Collisions in South Dakota. Report to the South Dakota Department of Transportation, SD2014-03-F.

Donaldson, B. and N. Lafon. 2008. Testing an integrated PDA-GPS system to collect standardized animal carcass removal data. Virginia Transportation Research Council. URL: http://www.virginiadot.org/vtrc/main/online_reports/pdf/08-cr10.pdf

Olson, D. D., J. A. Bissonette, P. C. Cramer, A. D. Green, S. T. Davis, P. J. Jackson, and D. C. Coster. 2014a. Monitoring wildlife-vehicle collisions in the information age: how smartphones can improve data collection. *PLoS ONE*, 9(6): e98613. DOI:10.1371/journal.pone.0098613

Shilling, F.M. and Waetjen, D.P. 2015. Wildlife-vehicle collision observation collection and hotspot identification at large scales. *Nature Conservation*, 11: 41-60. doi: 10.3897/natureconservation.11.4438

Waetjen, D.P. and F.M. Shilling 2017. Large extent roadkill and wildlife observation systems as sources of reliable data. *Frontiers in Ecology and Evolution. doi: 10.3389/fevo.2017.00089*

US Department of Transportation. 2013. Guidance on treatment of the economic value of a statistical life in U.S. Department of Transportation analyses. URL: https://www.transportation.gov/sites/dot.dev/files/docs/VSL%20Guidance%202013.pdf