Automated Analysis of Wildlife-Vehicle Conflict Hotspots Using Carcass and Collision Data

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16. Abstract States increasingly maintain databases of wildlife-vehicle conflict (WVC), including locations of carcasses and crashes involving animals. Once these data are collected, a common and expensive barrier before they can be used in safety and environmental planning is identification of "hotspots" of incidents (here defined as locations of high-rates and/or statistically-significant clusters). In this project, we developed a web-based analytical environment that state DOTs can use to automate certain analyses of WVC hotspots in order to inform planning to improve driver and wildlife safety. Specifically, we coordinated with staff from 3 states: Idaho, Nevada, and Maine, and used data that we had for California to develop the pilot automated hotspots analysis tool. We tested several methods for representing both density and statistically-significant clustering of WVC events. These were implemented in the statistical package R and driven by scripts that can operate in the project web-system. Testing was conducted using California data while other states prepared/delivered their data. We developed hotspots analyses for California, Maine, Idaho, and Nevada based upon their input. We prepared a web-system to operate the tool (https://roadecology.ucdavis.edu/hotspots), that DOT staff from 13 states used so far with their own data.		
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About the Pacific Southwest Region University Transportation Center

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The Pacific Southwest Region UTC conducts an integrated, multidisciplinary program of research, education, and technology transfer aimed at *improving the mobility of people and goods throughout the region*. Our program is organized around four themes: 1) technology to address transportation problems and improve mobility; 2) improving mobility for vulnerable populations; 3) improving resilience and protecting the environment; and 4) managing mobility in high growth areas.

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Disclosure

Fraser Shilling, Cameron Denney, and David Waetjen conducted this research, entitled, "Automated Analysis of Wildlife-Vehicle Conflict Hotspots Using Carcass and Collision Data," at the University of California, Davis. The research took place from October 1, 2017 to January 31, 2019 and was funded by a grant from the U.S. Department of Transportation in the amount of $133,040.56. The research was conducted as part of the Pacific Southwest Region University Transportation Center research program.

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Abstract

Wildlife-vehicle conflict (WVC) refers to any interaction between wildlife and vehicles/traffic that can have negative impacts for drivers and/or wildlife. When drivers swerve because of animals on the road and crash, or when vehicles collide with larger animals, this can result in damage to the vehicle, and injury and sometimes death for drivers and passengers. There is some predictability to WVC that can be highlighted by studying past WVC events. Most states and countries use past WVC occurrences as a source of information for planning mitigation to improve driver safety and to protect animals. This report covers: 1) critical elements of data collection needed to inform hotspots analysis; 2) overview of an automated online tool that provides any U.S.-state user a way to map densities and statistically-significant clusters of WVC (https://roadecology.ucdavis.edu/hotspots); and 3) next steps in automating data collection, management, reporting, and use in decision-making. We built a real-time WVC reporting system for California, which could be used to inform driver-assist programs in conventional and automated vehicles. The automated analysis tool was developed in partnership with several state DOTs to ensure utility for state agencies. The tool uses state and interstate highway maps divided into 1-mile segments, user-uploaded datasets and returns to the user analysis outputs in several forms.

Automated Analysis of Wildlife-Vehicle Conflict Hotspots Using Carcass and Collision Data

Executive Summary

Wildlife-vehicle conflict (WVC) refers to any interaction between wildlife and vehicles/traffic that can have negative impacts for drivers and/or wildlife. This includes animals fleeing from traffic noise/light, to drivers swerving around animals on the road surface, to vehicle collisions with animals. When drivers swerve because of animals on the road and crash, or when vehicles collide with larger animals, this can result in damage to the vehicle, and injury and sometimes death for drivers and passengers. Although there are always some aspects of WVC that are difficult to predict (e.g., when an animal might decide to cross a road), there is also some predictability to WVC that can be highlighted by studying past WVC events. Most states and countries use past WVC occurrences as a source of information for planning mitigation to improve driver safety and to protect animals. This report covers: 1) critical elements of data collection needed to inform hotspot analysis; 2) overview of an automated online tool that provides any U.S.-state user a way to map densities and statistically-significant clusters of WVCs (https://roadecology.ucdavis.edu/hotspots); and 3) next steps in automating data collection, management, reporting, and use in decision-making. We will discuss a novel real-time WVC reporting system for California, which could be used to inform driver-assist programs in conventional and automated vehicles. The automated analysis tool was developed in partnership with several state DOTs to ensure utility for state agencies. The tool uses state and interstate highway maps divided into 1-mile segments, user-uploaded datasets, and returns to the user analysis outputs in several forms. The approaches used here are identical to those used in the scientific and technical literature, providing the user assurance that the results can be used in planning.

State Partners

We received invaluable assistance from several state Departments of Transportation (DOTs) and Departments of Wildlife, or similar. Staff from the Maine Departments of Transportation and Inland Fisheries and Wildlife; Nevada Department of Transportation, and Idaho Department of Fish and Game provided spatial datasets of WVC and suggestions for use of their data and development of a web-tool that other states could use to automatically analyze WVC data. We also used data for California collected by the California Highway Patrol, Caltrans Maintenance staff, and volunteers with the California Roadkill Observation System. We used data and suggestions from partner states to pilot analytical approaches in the statistical package R and to develop the web-system that operates the automated analyses. Once the web-tool was developed, we benefited from beta-testing of the tool by staff from the Colorado DOT, Maine DOT and Inland Fisheries and Wildlife, Minnesota DOT, Nevada DOT, New Jersey DOT, Texas Parks and Wildlife Department, Vermont Agency of Transportation, and Virginia DOT. Their feedback was used to refine development of the web-tool.

Introduction

WVC is a large and growing concern among DOTs, conservation organizations and agencies, and the driving public (Huijser et al. 2008). WVC is a safety concern for drivers (Bissonette et al. 2008) and a conservation concern for most animal species (Fahrig and Rytwinski 2009). Loss et al. (2014) estimated that between 89 and 340 million birds may die per year in the U.S. from collisions with vehicles. Predicting and prioritizing places to mitigate the impacts to wildlife and drivers is an important step in reducing the WVCs. Many DOTs are trying different methods of reducing WVC, including fencing roadways and providing crossing structures across the right-of-way to allow safe animal passage. WVCs occur when traffic coincides with a place where animals decide to cross the surface of a roadway. One common finding with spatial analysis of WVCs is that collisions are clustered, which often leads to analysis of proximate causes of clustering for individual species (e.g., road or landscape features; Gunson et al. 2011). One approach is to use previous collisions to develop predictive landscape models to find "hotspots" (Nielsen et al. 2003; Langen et al. 2009; Gunson et al. 2011; Bil et al. 2013). To inform these types of predictions and corresponding mitigation on a large scale (e.g., a U.S. state), it becomes necessary to collect accurate, extensive, long-term WVC data.

Reducing impacts to wildlife and connectivity from roads and traffic requires understanding the degree and location of impacts and which species are impacted. This understanding is based on monitoring, which can inform adaptive management and actions (SWAP, Ch. 8; https://www.wildlife.ca.gov/SWAP/Final). For example, in San Diego County, biologists with the United States Fish and Wildlife Service (USFWS) have contributed data to the California Roadkill Observation System and have used the system to make recommendations about wildlife crossings to Caltrans during a highway project (John Martin, USFWS, personal communication). Wildlife biologists and managers need to understand how significant such impacts are for animal populations, especially those listed by the U.S. Geological Service as Species of Greatest Conservation Need. This understanding is necessary to plan appropriate mitigation strategies. The aim of the project reported on here was to develop a reusable method to turn roadkill observations into information to support mitigation planning to reduce impacts.

DOTs and scientists typically focus on three types of clusters of WVCs: a) high-densities of crashes or carcasses of all or specific taxonomic groups, b) statistically-significant clusters of crashes or carcasses, and c) combinations of statistically-significant and high-density clusters. There are many tools to measure impacts to species from WVCs, to determine causes and correlations with WVCs, and to identify places where transportation agencies can focus remedial action to reduce impacts to wildlife and improve driver safety. Examples of analytical approaches and methods include: Nearest Neighbor Index (e.g., Matos et al. 2012); 'Satscan', borrowed from epidemiological studies, which looks for non-random clusters of events (i.e., disease outbreaks, Ball et al. 2008); the Getis-Ord Gi statistic for spatial autocorrelation (Getis and Ord 1992); the Moran's I statistic for clustering (Asselin, 1995); and the Kernel Density Estimator Plus (KDE+) method for estimating locations of high densities of events (Bil et al., 2013).

Approach

Development Process

We contacted representatives from partner state Departments of Transportation and Wildlife and engaged them individually in discussions about sharing their WVC data, developing the tool, and the desired outputs from the tool. Members of DOTs, Departments of Fish and Wildlife, and local agencies participated from CA, CO, ID, ME, MN, NJ, NV, TX, and VA. This technical advisory group provided useful initial discussions about barriers they had to implementing WVC mitigation, including availability of data, accessibility of data analysis, and willingness of other DOTs to recognize and collaborate on solutions. Several states helped develop the web-system (described in detail below) and took advantage of it to carry out analyses that they found useful.

California

Incident data were collected by the UC Davis Road Ecology Center's "California Highways Incident Processing System" (CHIPS) from the California Highway Patrol (CHP) website (https://cad.chp.ca.gov/traffic.aspx) starting in February 2015. The database was then queried for incidents involving animals to create a dataset of WVC (n = 8,588 between 2/2015 and 2/2017). The CHIPS WVC data includes collisions between vehicles and wildlife, carcasses found on highways, traffic hazards caused by animals, and other types of traffic incidents involving animals. Large mammal carcass data from the California Roadkill Observation System (https://wildlifecrossing.net/california) were also used as evidence of a collision.

Idaho

WVC incident data for Idaho were obtained from the Idaho Department of Fish and Game (IDFG). The IDFG collects roadkill and salvage reports and provides public access to download the data. The set contains 24,924 reports starting at the beginning of 2013 through September 9, 2017. Most records are collected by public agencies like IDFG and Idaho Department of Transportation. Some records are collected by individuals reporting roadkill online. The Idaho data are primarily an inventory of animal roadkill, including citizen sourced reports, not of traffic incidents.

Maine

The data obtained from Maine contained 30,062 records of carcasses resulting from WVC, from 2004 to 2013 collected by Maine Department of Transportation. The Maine dataset is exclusively of deer carcass collection along roadways.

Nevada

The Nevada dataset contained 5,189 records of carcasses resulting from collisions between 2007 and 2016. It was collected by the Nevada Department of Transportation. Of the data points, 53% are deer, 14.8% cattle, 7.5% horse, and 6.5% dogs or coyotes, with several other species listed in small quantities.

Highway Spatial Data

The basis for the WVC network analysis is the highway network. In order to create a uniform unit for analysis, analogous to raster cell resolution, one-mile segments were created for highway networks. The California's State Highway Network (SHN) and the National Highway Planning Network (NHPN) for California were used for the WVC analysis of California, while the NHPN dataset was segmented to create uniform and structurally consistent datasets for all other U.S. states.

The SHN vector data contains all state, interstate, and federal highways in California. There are two polylines for each highway alignment: left and right. For most of the analysis, only highways listed as 'right' were used. This was done to avoid inconsistencies in geoprocessing caused by duplicate lines. The left and right lanes spatially overlap for most of the network, but, in some sections of highways, lanes diverge from one another. For example, the left and right lanes of Interstate 5 in Northern California near Shasta Lake are ~1,300 m (4,000 ft) apart for a short distance. In this case, both lanes were used when determining which CHIPS points to include in the study, but only the right lane was incorporated in the hotspot analysis. Since the SHN is the standardized, publicly available dataset for Caltrans, it was used as the primary network for analysis in this study.

In the analysis, first the lines representing highways in California on the SHN were split every mile, at the postmile marker. This created a fairly uniform set of segments, split at well-known locations. In ArcMap, SHN roads were also split every mile, at the postmile marker, using the "Split Line at Point" function in the data management toolbox. Segments less than 500 meters were removed, most of which were short because of crowded line topology caused by intersections. Caltrans reports that the state has 14,832 centerline highway miles (2013 State of the Pavement Report – Caltrans). The resulting highway segments for this analysis comes acceptably close, with 14,930 miles of roads cut into 14,956 segments. The average segment was .997 miles in length, with a standard deviation of 208 meters (0.13 miles).

For the NHPN, a function in R (the statistical program) was used to accurately split highway lines into equal lengths to create one-mile segments (see references). First, all highways were dissolved to create a single line feature. Dissolving removes most topology issues when cutting the lines into segments. Then, the previously mentioned function was used to cut the NHPN into one-mile segments. Finally, a spatial join was used in ArcMap to return original attribute data to the one-mile segments. Most of the joined data were not directly used in this study but may bolster future research. In the end, the NHPN segmentation process created 482,862 line segments, of which 398,699 (83%) were exactly one mile. The remaining segments were all less than one mile and represent short roads or the ends of segments. We decided to not merge the ends of segments, which would create some segments longer than one mile, so no segments are longer than one mile. Overall, segmenting the SHN and NHPN created a nearly uniform set of segments, with associated data, to use for WVC analysis. Also, after all the previous processing steps, no significant losses or gain in highway length was detected. The segments represent 436,400 (99.9%) of the original 436,891 miles on the NHPN dataset.

Next, an R script was written to assign WVC incident points to spatially corresponding road segments. The R script uses the "SnapPointsToLines" function in the maptools library. Points further than 50 meters from any segment were filtered out. This allows for some spatial inconsistencies caused by data collection but does not attribute incidents to incorrect road segments (e.g., from nearby local roads). Then, the number of WVC incidents for each segment was totaled and added as an attribute field to the segment attribute data. The number and percentage of total incidents included were returned to the original dataset. The result was the total number of incidents per mile 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 state agencies often record 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 will include WVC points on roads not in the analysis, inaccurately inflating density distribution. Fifty meters was chosen because it would include points collected on the shoulder several lanes from the road centerline in both directions, but not points further than 50 meters that may actually have occurred on other roads. This included about 73% of incidents.

Statistical Analysis

To provide further analysis on the spatial distribution of WVC along the network, the tool automatically calculates spatial statistics using the incident density per 1-mile segment. The Getis-Ord Gi* statistic was primarily used to create a hotspot score for each one-mile road segment. An R script runs 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 (1,609 meters), and a binary weighted matrix includes 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 distributions, however, the resulting z-score is not clearly understood by all audiences. 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. Also, negative Gi* values are assigned a hotspot score of zero, as negative Gi* values indicate the segment has a low incident density in a region of low densities. Then, a percentile of each Gi* value within the distribution of remaining non-zero segments was calculated. Finally, an integer value from 1–10 was 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. For example, a Gi* score of +6.0 would be in the 95th percentile in California. If WVC incidents have been reported within this segment, then it would be assigned a hotspot score of 10.

Web-System

The web-system at https://roadecology.ucdavis.edu/hotspots provides the interface for the user to upload data and receive analysis outputs for the data they have uploaded. It handles all user interactions through an account and allows the user to store and manage data and analytical accounts, including deleting them once they have finished.

User Registration and Data Upload

The system provides an interface where any user can register for an account by entering their email address, select a “username” identifier, and the name of the organization they are affiliated with—we collect the user’s organization to be better understand the type of users who are using the tool. The user receives an email with their login instructions, and once logged in, taken to a screen where they can create an analysis.

When the user initiates the creation of an analysis, they are presented with several fields to fill in. The user has an option to upload an Esri shapefile which contains their point data, or they can upload a text-based CSV file. If the user uploads a shapefile, the system will automatically detect and re-project the data into a format it can use. When a CSV file is uploaded, the user is required to tell the system the exact name of the columns that contain the point data (e.g., “Lat/Lon” or “Latitude/Longitude”) and requires the points to be in a standard WGS 84 coordinate system.

The user then selects a state where the analyses will occur. Currently, only U.S. state highways can be used in analyses. Choosing a state will select the underlying roads layer which is required for the procedure. This tool supports analyses at sub-state extents, but does not currently support cross-state analyses. Once the user clicks “Save,” their analysis is put into a queue for processing.

Analysis Support

For returning users, the user’s “homepage” lists any of the previous analyses they have run. The tool stores their data indefinitely, and it is up to the user when and whether to delete their past analyses, and we have found that some users prefer to do that. For any issues that arise in the system, the users can generally contact the Road Ecology Center, and we work with them to resolve their problems or issues. So far, the support cases have revolved around formatting issues with the uploaded data, which are readily solved.

Analysis Outputs

Upon successful completion of an analysis, there are three main outputs for the user. The first is the log file, which contains reports of the analysis steps and preliminary output from various analytical steps. This includes the number of points removed by the filtering process, the number of points used in the analysis, Moran I statistic and p-value, the Monte-Carlo simulation of Moran I, and the Getis-Ord global G statistic and p-value. The tool also exports a shapefile containing the state highway line segments with statistical results as attributes, as well as an interactive map to visualize their data in a web interface. Lastly, the tool exports two fairly high-resolution images of results (in .png format), which the user can use in reports and presentations.

Future Enhancements

The system could be enhanced to export results as part of a report that not only shows the values of the statistic and p-value, but provides context for the value and what the results mean. Currently, the system runs the analysis and reports the results, but much of the interpretation of the results rests on the user. With a little more time, we could make significant improvements to the package delivered to the user. In addition, we have had requests for use of the tool in Mexico and Canada, but because the project was supported by USDOT funds, we restricted use to the U.S.

Results

We developed and tested four versions of the overall system: 1) a desktop version of the automated processing of data, R analyses, and outputs; 2) an “alpha” version of the web-system that automates spatial data processing, analysis, and publication of products; 3) a “beta” version of the web-system for external testing by partners; and 4) a final version of the web-system.

We developed automated production of several types of outputs from the analyses that we thought might be useful to potential users of the web-system. The first product is an image file (jpeg) of the map output (Figure 1), which is intended to show the users a graphical representation of the results. We also provide an html file (Leaflet map), which shows quickly and in a browser view what the spatial dataset contain. The Leaflet map provides the user with a “mini-GIS” where they can click on different check boxes and see different analysis products (Figure 2).

Figure 1. Image file output for WVC incident density in MN. Darker red indicates greater incident density (Data, analysis and image courtesy MNDOT).

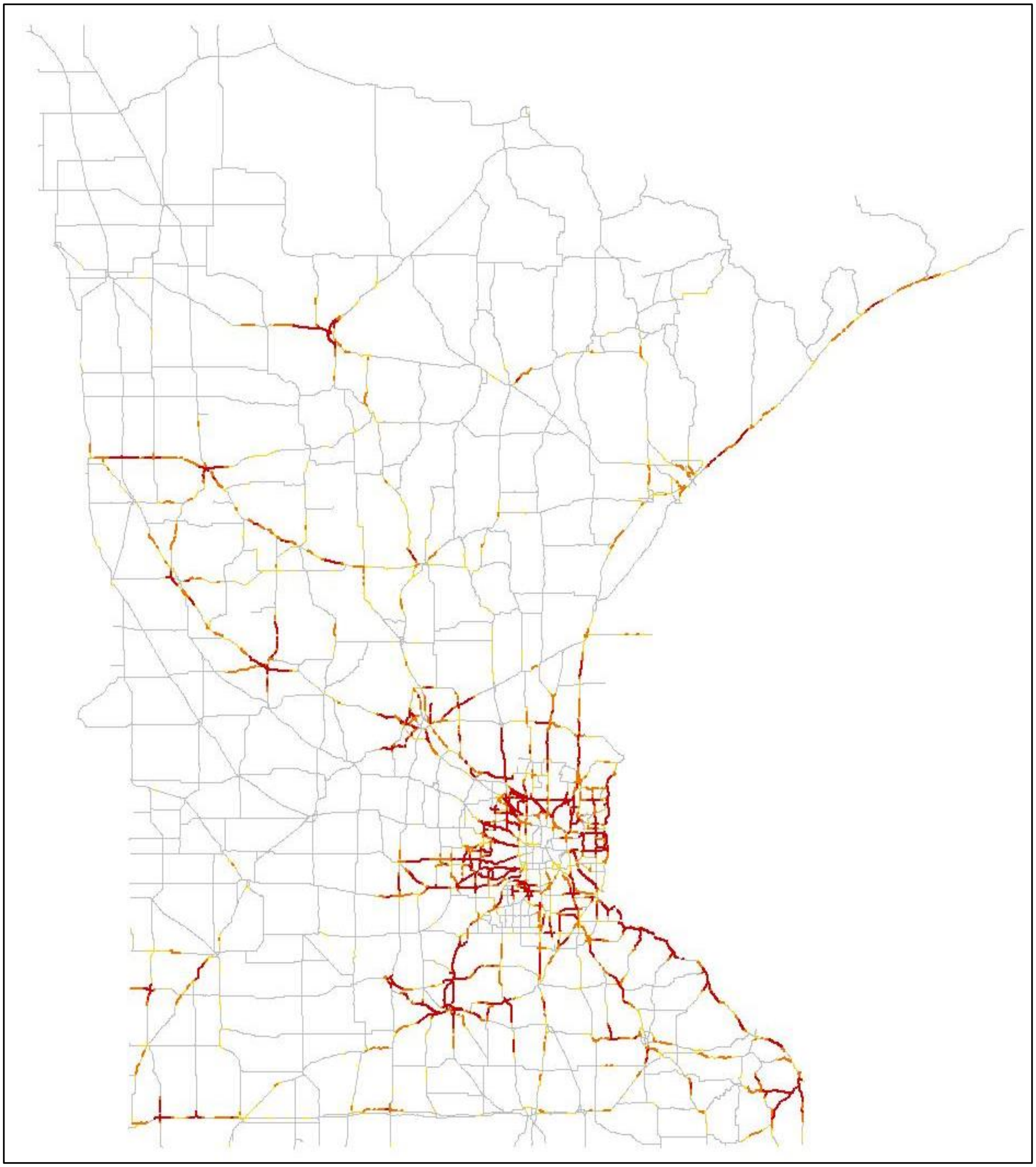
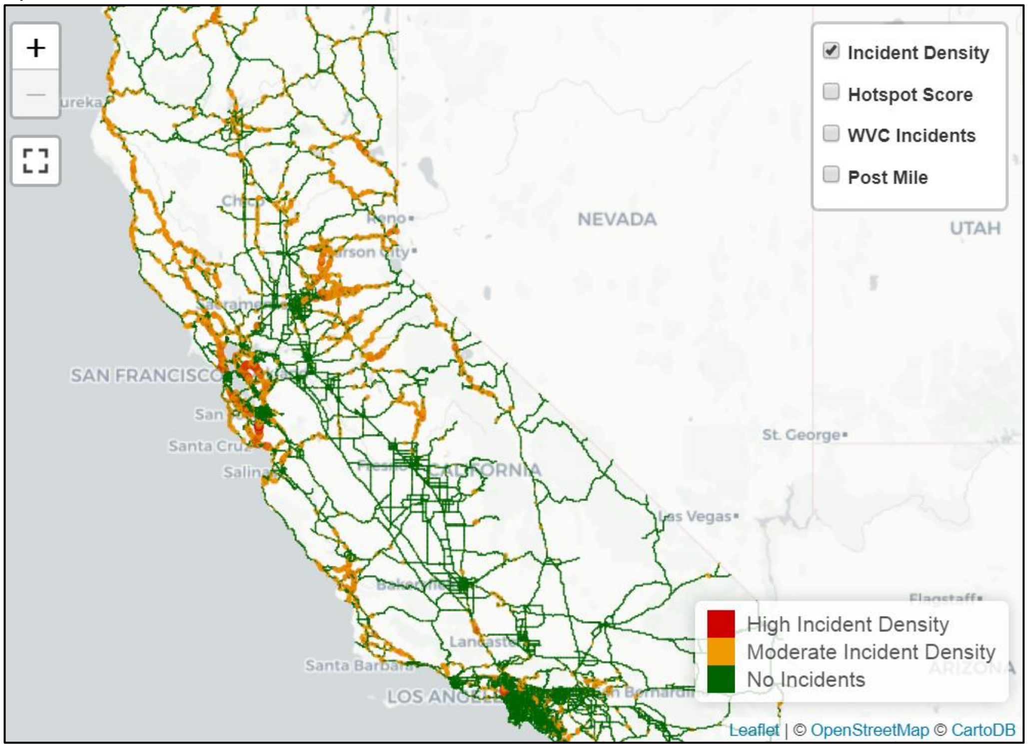
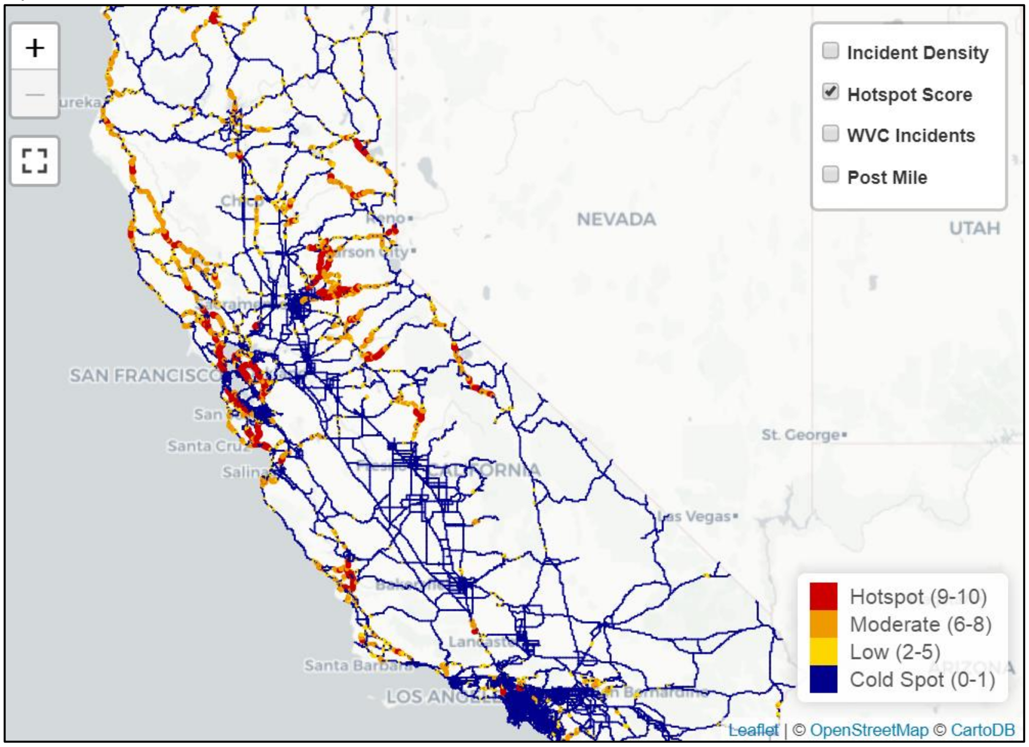


Figure 2. Automated production of a Leaflet map (.html file) showing the calculation of (a) WVC incident density and (b) WVC incident clustering for California highways.

a)



b)



The hotspot analysis tool is designed for a variety of users, with varying interests and levels of technical skills. Therefore, the tool produces multiple complimentary outputs, enabling diverse stakeholders to find utility in the product.

Descriptive statistics and information about the WVC dataset are available to the user through their account, as well as an interactive web map with multiple layers of data. The web map is created using R, through the *leaflet* package. Interactive web maps are commonly used in applications such as Google Maps and open street maps, and they are therefore more likely to be familiar to users. The ability to zoom and pan on a web map allows users to investigate regions of interest at multiple scales. Furthermore, multiple layers can be incorporated into the map, allowing users to select which types of information to display. This style of data visualization enables stakeholders with diverse interests to find utility in the analysis without knowledge of GIS or access to proprietary software.

The shapefile output contains the highway network in one-mile segments, with relevant attributes attached to each segment. These attributes include the number of WVC incidents, the hotspot score, annual average daily traffic (AADT), post-mile, and many other fields. These files will be valuable for further analysis of WVC. For example, the dataset would enable analysis into the relationship between WVC density and traffic volume, or proximity to specific habitats.

State-Specific Results

California

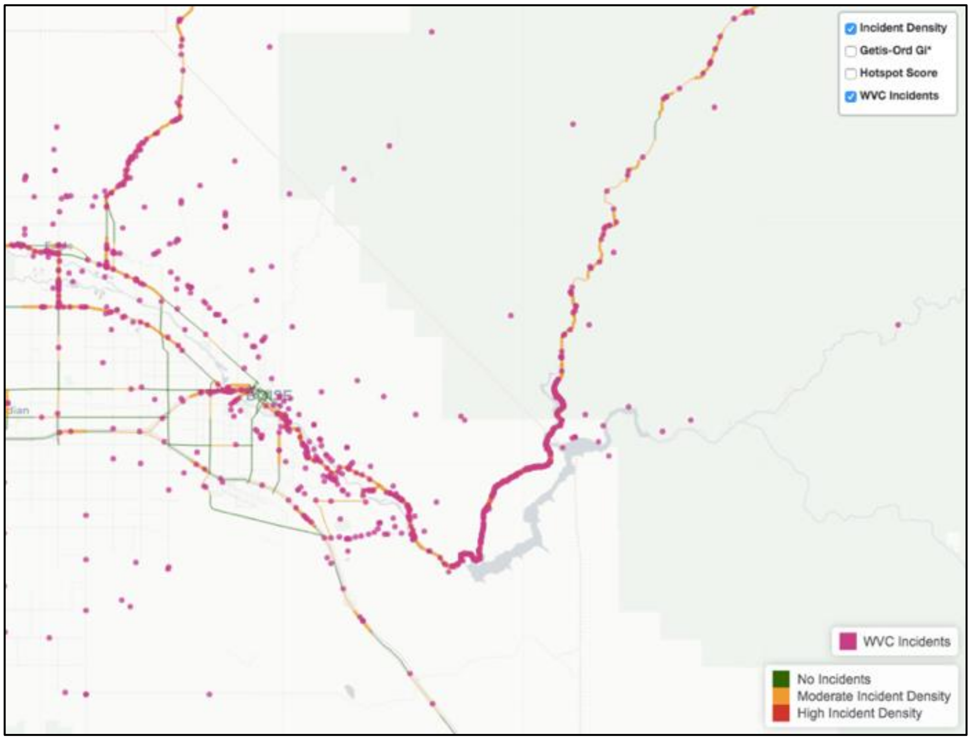
California WVC hotspots occur in several regions, but nearly 90% of segments with a hotspot score of 10 are around the San Francisco Bay area, or between Sacramento and Lake Tahoe (Figure 2). WVC density appears to peak in areas with high traffic volume passing through regions with habitat suitable for large mammals. Significant WVC density is rare in dense urban areas and on rural roads where animals are likely present but traffic volumes remain low. The hotspot score identifies locations of highest statistical and potential impact significance.

Idaho

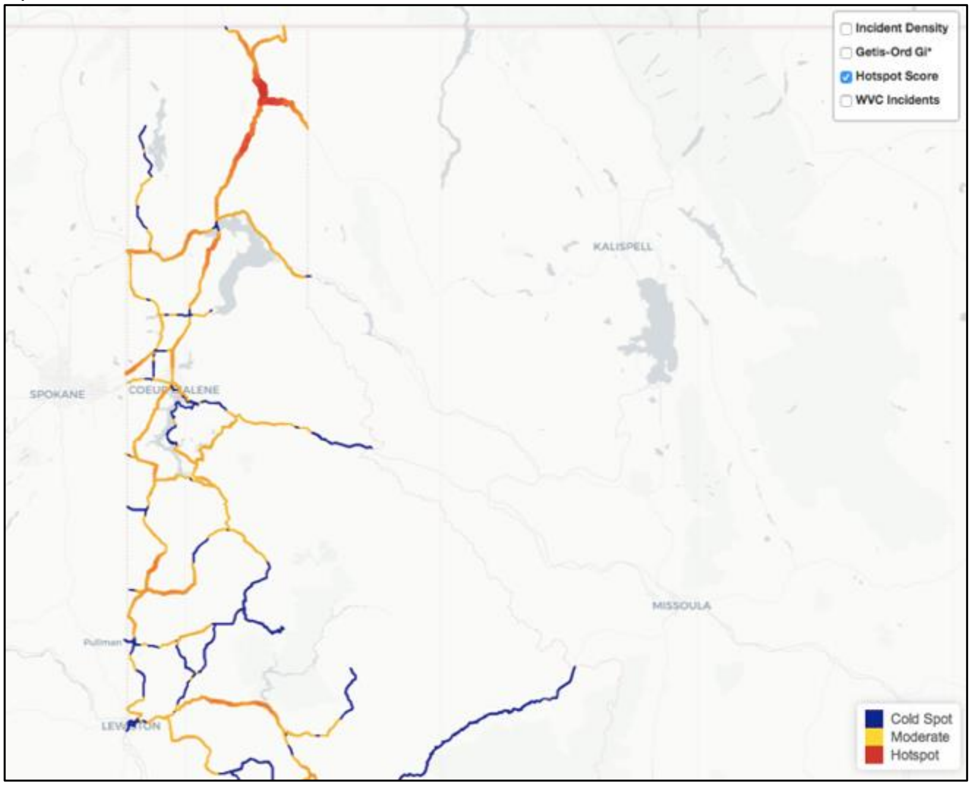
Most WVC hotspots in Idaho appear in the northern panhandle, and just outside of Boise, the largest urban area in the state. Some hotspots with significant density are present in south-eastern Idaho as well, mostly along major highways. Figure 3 shows examples of mapped incidents and hotspot scores returned to the user.

Figure 3. (a) WVC Incidents around Boise, ID; and (b) Hotspot scores in the Idaho panhandle.

a)



b)

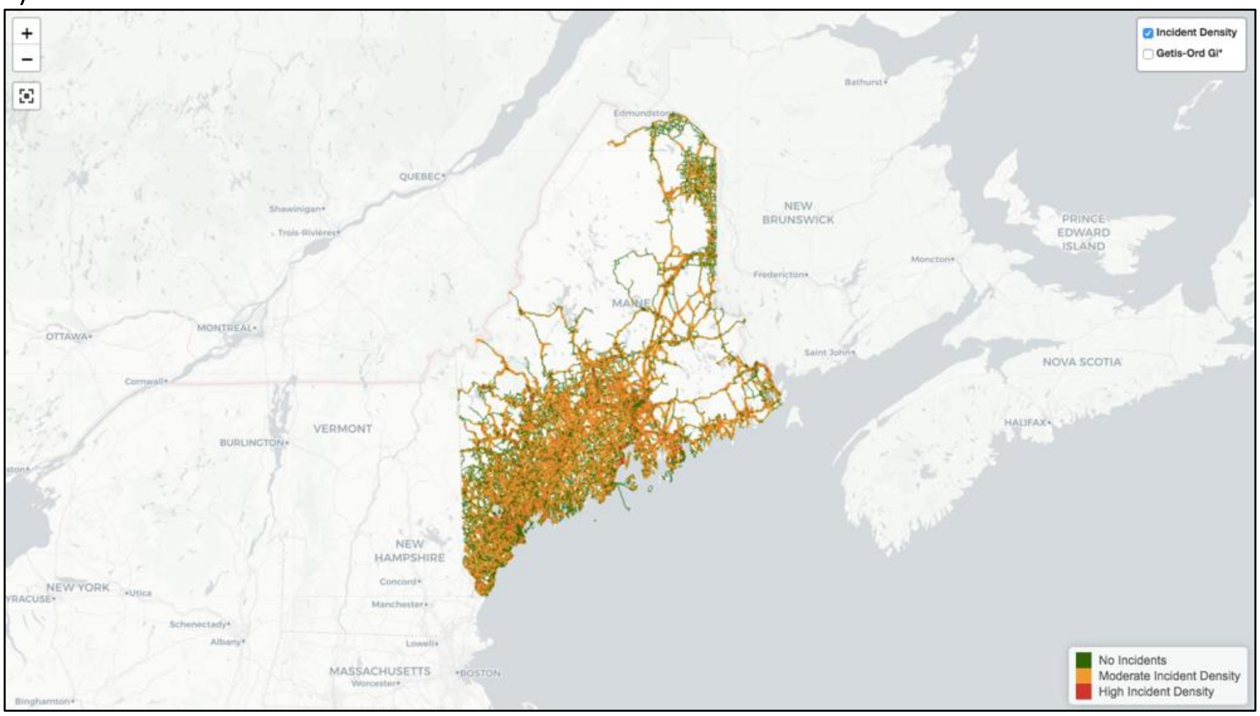


Maine

Maine's state-managed roadway network is substantially denser than Nevada's and Idaho's, as are the WVC incidents. WVC is distributed more evenly across the network than in other states, suggesting less clustering (Figure 4). Therefore, WVC hotspots in Maine appear dispersed. While this may be partly due to Maine collecting more years of WVC data than the other three states, WVC distribution is likely much different in Maine than in the other states. This likely is because land use, roadways, and habitat across Maine are more evenly distributed than the other states analyzed, and therefore exhibits less spatial autocorrelation than California, Nevada, and Idaho.

Figure 4. a) Maine WVC incident density and (b) WVC Density in coastal Maine.

a)



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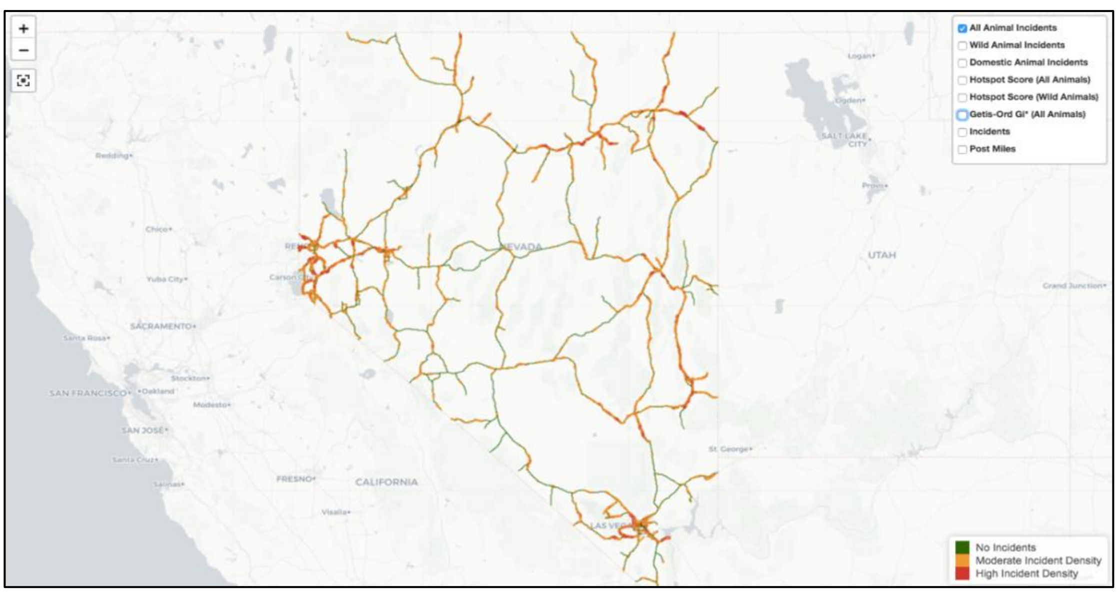
b)

Nevada

Nevada has relatively few state-managed roads compared to the vast area of the state. WVC in Nevada shows strong spatial autocorrelation, with distinct hot and cold spots along highways (Figure 5). WVC hotspots emerge just outside of the two major cities—Las Vegas and Reno—as well as along some of the highways with substantial AADT—I-80 and US-93.

Figure 5. Density of WVC (domestic and wild animals) on NV highways.



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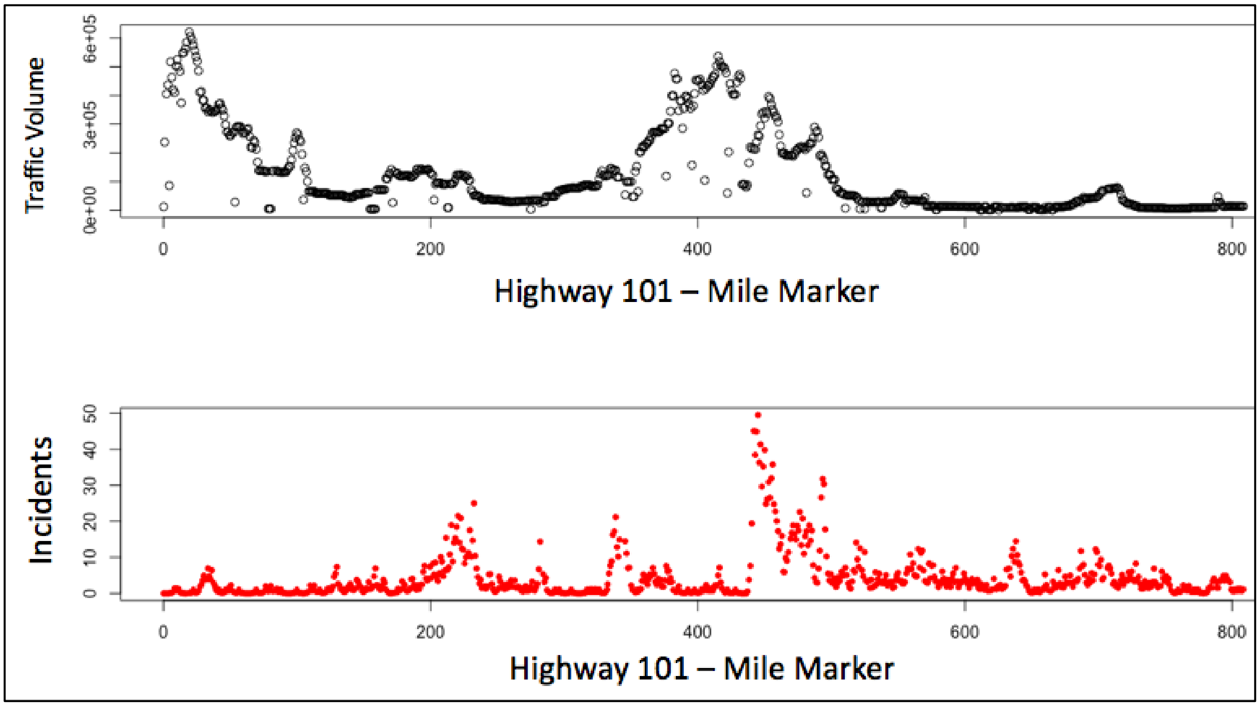
WVC Outcomes

Some WVC datasets include incident outcomes, allowing for a glimpse into the severity of incidents. Unsurprisingly, humans usually fare better than wildlife, although human injuries and fatalities do occur. For example, in CA 42% of animals die during WVC, 21.5% are injured, 8.2% are known to be alive with no injury, and the remaining 28.3% unknown. Thirty-five percent (3,129 of 12,142 incidents) have driver outcome data completed. Of these, 79.8% report no human injury, 3.6% report minor injury, and 0.7% major injuries. Five human fatalities are reported in the 2 years of CA WVC data, representing 0.2% of records with completed driver outcome records. Property damage also occurs frequently in WVC incidents. This is presumed to predominately be damage to vehicles and road infrastructure. The CA data includes information on carcasses collected by the CHP but not for those collected by other agencies, such as Caltrans, by individuals, or not collected at all.

Traffic and WVC

Traffic volume has a complex, yet significant impact on WVC. Of course, without the presence of both cars and wildlife a WVC incident cannot occur. However, areas with the highest traffic volumes are often in urban areas, with few to no animals present. On the other hand, some roadways with nearby large mammal populations may not have enough traffic volume to incur high densities or statistically significant clusters of WVCs. Some places, however, have moderate to high traffic volumes and large mammals present. If the roadway geography and infrastructure allow wildlife access to roadways in these regions, high WVC density can occur. For example, Figure 6 shows US-101 in California from south to north. It compares AADT with WVC incident density (CHIPS data 2015–2017). US-101 begins in Los Angeles (mile marker “0”), with correspondingly high traffic volume (AADT). Few incidents occur in the LA area, likely due to low large mammal populations in a dense urban area. In northern California, traffic volumes increase tremendously as US-101 enters the San Francisco Bay Area (>mile 350). At first, WVC remains low, until leaving San Francisco and entering Marin County by crossing the Golden Gate bridge (>mile marker 430). After the bridge, WVC density immediately increases and enters a 20-mile stretch of some of the highest density and strongest clustering in the state of California.

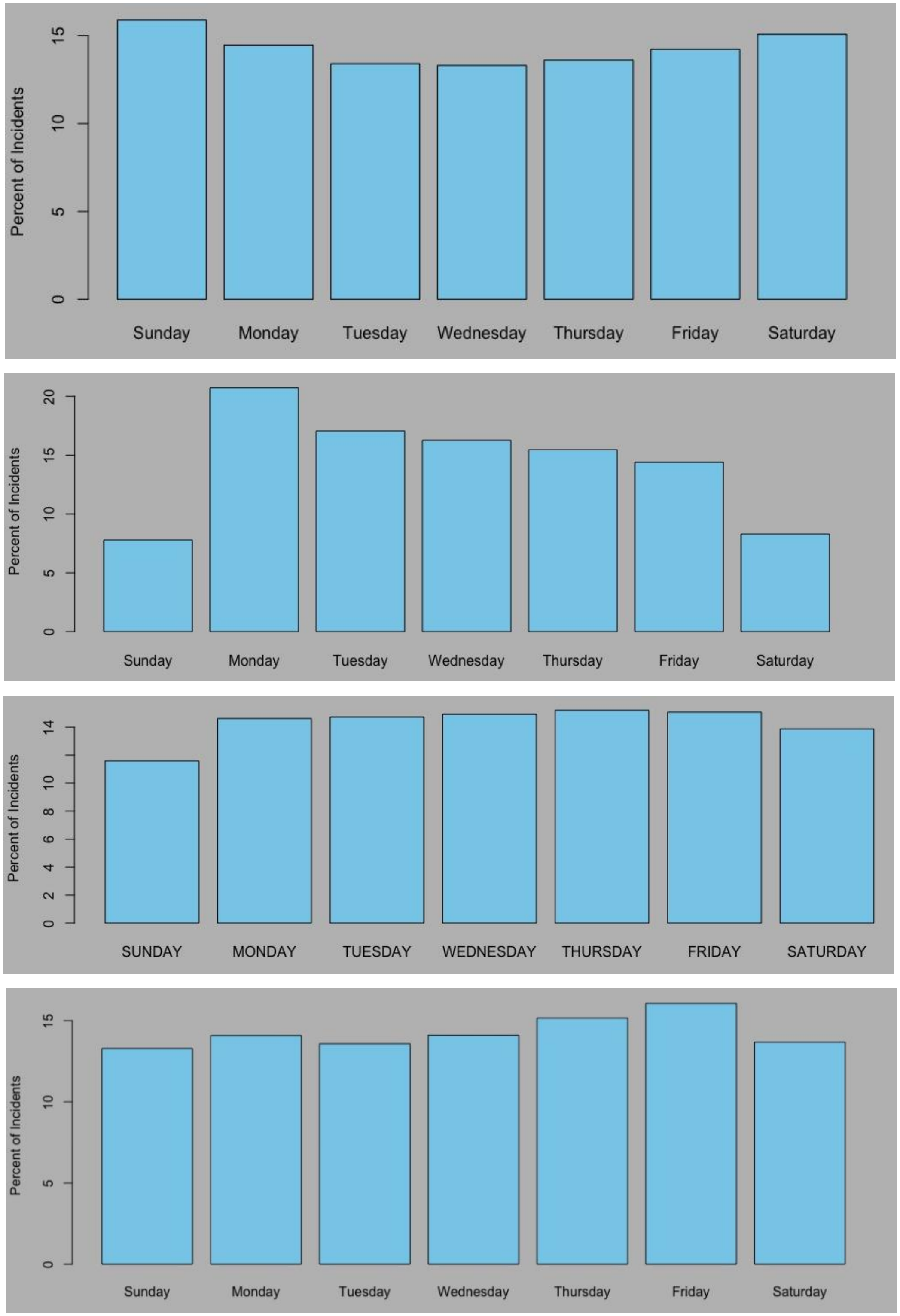
Figure 6. Traffic volumes (black circles, upper graph) and WVC incidents (red points, lower graph) at mile markers along highway 101.



Temporal Analysis

Because WVCs can vary temporally as well as spatially, the tool automatically returns descriptive temporal statistics to the user. WVC incidents show variation over time of day, day of week, seasonal of year, and year to year. Although reports of WVC incidents often contain the exact reporting time, which may correlate with the time of the incidents, this is not always the case, and for reports of carcasses, report time does not necessarily correlate with when a collision occurred. Variation in WVCs within weeks is usually slight but can vary among states (Figure 7). There may be several explanations for this phenomenon, but the shifts are likely related to driver activity. Changes of traffic flows, both in volume and location, may contribute to day-to-day shifts in WVC. Also, data collection methods may play a role in differences among states. CA WVC incidents are collected by law enforcement; in other states data are collected by DOTs, which work more during weekdays.

Figure 7. Proportion (%) of WVC by day of the week for: A) California, B) Idaho, C) Maine, D) Nevada.



A

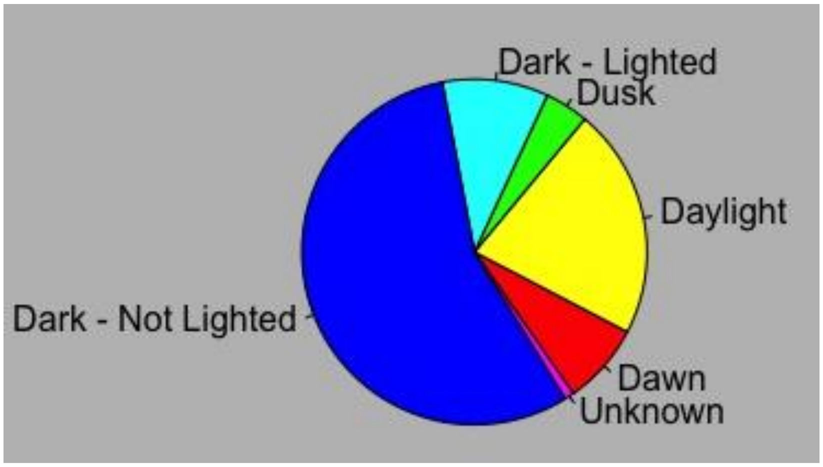
B

C

D

Time of day influences WVC occurrences. In Maine, the majority of WVC occur in the dark (56%) with a smaller proportion occurring in low-light conditions (dawn, dusk, dark-lighted) and daylight (Figure 8) Overall traffic volumes probably decrease during dark hours, suggesting that WVC increases on dark roads without street-lights.

Figure 8. Deer-related WVC under different lighting conditions.

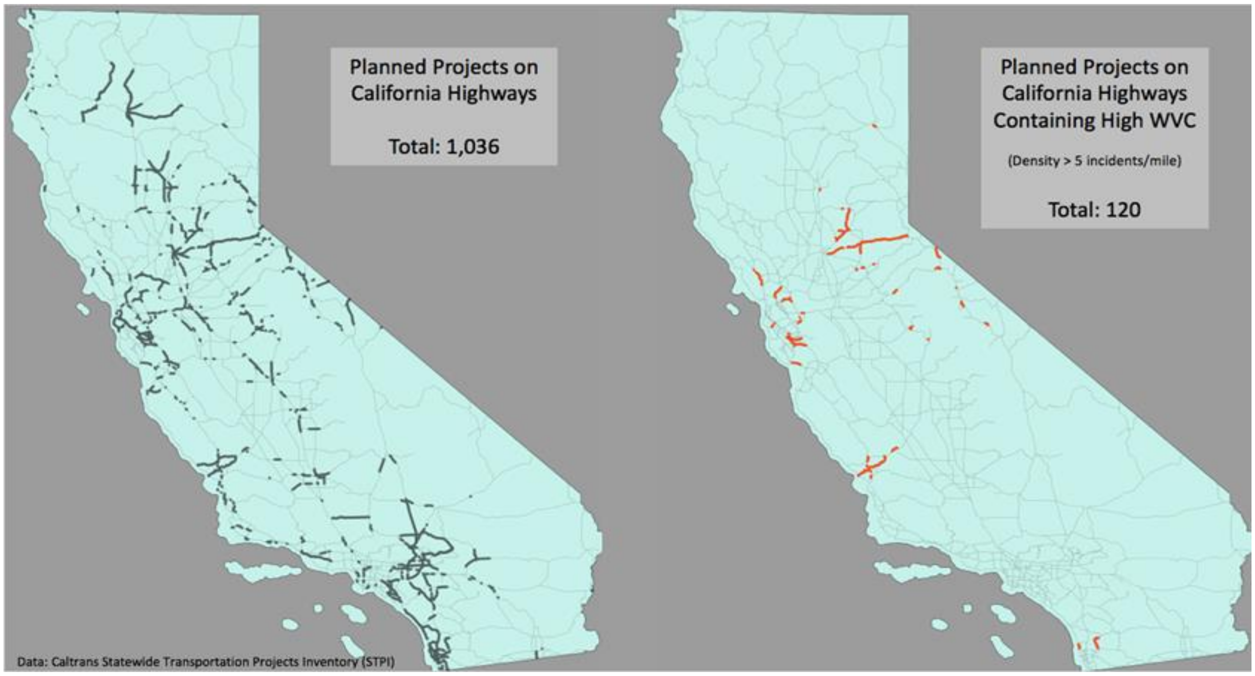


Variation also occurs annually. In Nevada, Maine, and Idaho, record collection has been consistent over the last decade, so inter-annual variation can be assessed. In all 3 states, there was a roughly 10–20% fluctuation in rates of WVC.

Overlap Between Hotspots and Proposed Transportation Projects

As of November 2017, the California Statewide Transportation Projects Inventory (STPI) reported 1,036 planned projects on the SHN (Figure 9). Almost 20% (2,287/12,142) of CHIPS incidents fall within 100 meters of these projects. Of the 1,036 projects, 120 include road segments with high rates of WVC (hotspot score of >8; WVC density >3/mile, Figure 9). While these projects vary in objectives and scale, mitigation measures to decrease WVC could be considered since construction will already be underway. This analysis can directly inform infrastructure design decisions on projects, based on WVC density and clustering.

Figure 9. Examples of proposed CA projects and projects with high WVC.



The purpose of wildlife crossing structures is not solely to reduce WVC. The planned Liberty Canyon crossing just north of Los Angeles, for example, seeks to re-connect mountain lion populations across US-101. The region where the crossing structure will be placed is not a 'hotspot' of WVC. However, several incidents involving mountain lions have occurred in the vicinity of the planned structure. While low WVC density may not seem to support the necessity of the crossing structure, it suggests that wildlife may not be able to access the roadway at all. Since US-101 splits a well-documented mountain lion habitat, and relatively few WVC incidents have been documented in the area, the analysis supports the need for a crossing structure in this location because it shows that, possibly due to robust fencing, steep terrain, high traffic volumes, or other barriers, wildlife are unable or unwilling to access the roadway. Therefore, populations have no connectivity across the highway. A crossing structure will provide safe access across the highway, re-connecting lion populations. While the presence of high WVC density shows danger to drivers and wildlife, moderate and low-density sections can also provide useful data for infrastructure and policy decisions. In this case, relatively low WVC density in a region of known wildlife populations, no apparent crossing structures, and high traffic volume indicate that wildlife are unable to access, let alone cross, the highway. Therefore, the Liberty Canyon crossing could effectively re-connect wildlife populations severed by US-101.

While the Liberty Canyon crossing is not in a section of high WVC density, similar projects occur near high incident density. Caltrans partnered with the Land Trust of Santa Cruz County and Santa Cruz County Regional Transportation Commission to plan a wildlife tunnel below state highway 17. The crossing will be located at what is known as the "Laurel Curve", a winding section of state highway 17 near Laurel Road. This region has high WVC density, with five consecutive one-mile segments containing ∼5 incidents/year. North of the project site, one segment has over 16 incidents per year. This example indicates that animals are present in the area and have easy access to the road. Moderate traffic volumes and curving roads likely exacerbate the likelihood for WVC as well. Although the Laurel Curve is not the site of highest WVC density, the structure may decrease WVC in surrounding regions.

When comparing data from multiple sources, the motivations behind the groups collecting data and the methods of collection are noteworthy. Collection methods play a critical role in the types of analysis methods readily supported by the data format. Data content drastically differs whether it was collected by law enforcement, departments of transportation, or citizens finding carcasses. Incident narratives written by the CHP, for example, typically include specific location information, physical descriptions of the humans involved in an incident, and an account of human activity. Individuals submitting carcass reports, on the other hand, often include more biological data about an animal such as age, species, and physical characteristics. Nevertheless, both methods produce WVC data sufficient for comparable spatial and categorical analysis.

Conclusions and Next Steps

WVC is a major driver safety and wildlife conservation issue for many state Departments of Transportation. One barrier to their working on solutions is carrying out geo-spatial analysis of WVC occurrences to determine where the highest densities and clusters of incidents occur. We developed an online tool for DOT staff and others to use to analyze WVC data for the occurrence of "hotspots," here defined as high densities or statistically significant clusters of WVC incidents.

Staff from 9 states participated in initial conversations to develop requirements for the system. User-supplied data from CA, ID, ME, and NV were used to develop and test the desktop version of the tool. Once the tool was working in the desktop environment, it was moved to an online location and opened to an invited group of beta testers. Users from CO and MN joined the initial group and the entire group repeatedly used the tool and reported any issues they encountered. Eventually, additional agency-users from NJ, WA, and the National Parks Conservation Association also created accounts to carry out analyses. As of April 9, 2019, over 36 staff from 27 local, state, federal, and private organizations from 15 states had used the analysis tool.

The novel tool provides an advancement for DOTs with WVC data and an interest in mitigating this safety and conservation impact. This indicates an unanticipated level of buy-in to the tool by partners beyond the original states. The approach is consistent with the scientific and safety literature and provides model outputs that users can export and use to support transportation decisions.

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Data Management

Products of Research

We developed an automated analysis tool to run through a web-service (https://roadecology.ucdavis.edu/hotspots) that any U.S. state user could use to analyze their data. We did not collect data during this process.

Data Format and Content

No data were collected from states using the tool

Data Access and Sharing

No data were collected from states using the tool

Reuse and Redistribution

No data were collected from states using the tool

Glossary

AADT	annual average daily traffic
Caltrans	California Department of Transportation
CROS	California Roadkill Observation System
CHIPS	California Highways Incident Processing System
CHP	California Highway Patrol
IDFG	Idaho Department of Fish and Game
NHPN	National Highway Planning Network
SHN	State Highway Network
USFWS	United States Fish and Wildlife Service
WVC	wildlife-vehicle conflict