Procedures and Tools for Wildlife-Vehicle Collision Hotspot Analyses; Using Caltrans District 10 as an Example

by

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This report contains a stepwise approach for the identification and prioritization of large mammal crash hotspots and large mammal carcass hotspots. Mule deer crash and mule deer carcass data from Caltrans District 10 were used as an example. The mule deer crash and mule deer carcass hotspots were ranked based on human safety, nature conservation, and economic parameters. Finally, mitigation measures were suggested for the deer crash and deer carcass hotspots. The mitigation measures were aimed at reducing the number of large mammal-vehicle collisions while still allowing wildlife to cross the road.</td></tr>
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This report contains a stepwise approach for the identification and prioritization of large mammal crash hotspots and large mammal carcass hotspots. Mule deer crash and mule deer carcass data from Caltrans District 10 were used as an example.

The authors of this report suggest that the first step is to define the problem; what is it exactly that may need to be addressed? Is it about reducing large mammal-vehicle collisions and improving human safety? Is it about a reduction of direct wildlife mortality on roads? Is it about better connectivity for wildlife across roads? For what species? In addition, a strategy needs to be chosen; can the problem be avoided altogether or do we need to accept the presence of the problem and do we strive to reduce the severity of the problem through mitigation and/or do we compensate for the problem by taking action elsewhere? For this particular project the main objective was to identify and prioritize road sections where human safety could be improved through reducing mule deer-vehicle collisions.

Mule deer crash and mule deer carcass hotspots were identified according to the following steps:
Step 1: Integrate the crash and carcass locations in a spatial database (ArcGIS format)
Step 2: Conduct a Kernel density (ArcGIS Release 9.3) analysis.
Step 3: Conduct an exponential regression analysis to identify where the crashes and carcasses may be disproportionately concentrated.
Step 4: Identify these road sections on a map.
Step 5: Identify additional road sections that may be considered for mitigation based on the density of crashes or carcasses (top 50 percentile).

The crash and carcass hotspots were ranked based on human safety, nature conservation, and economic parameters. The ranking for human safety was primarily based on the sum of deer crashes or carcasses in the individual hotspots, and, in case of a tie, also on the average number of deer crashes in a hotspot per 0.1 mi. The ranking for nature conservation was based on whether a hotspot was located in a core area (Natural Landscape Block) or corridor (Essential Connectivity Area) considered most valuable to nature conservation based on an existing statewide analysis. The ranking for economic parameters was based on an existing cost benefit model for mitigation measures aimed at reducing ungulate-vehicle collisions. The hotspots were ranked based on whether the costs associated with deer crashes or deer carcasses met or exceeded thresholds for four different types and combinations of mitigation measures, the sum of the costs associated with crashes or carcasses in the hotspots and the average cost associated with crashes or carcasses per 0.1 mi for the hotspots.

In general both the crash (n=14) and carcass hotspots (n=12) were located in the western foothills (about 396-1463 m (1300-4800 ft) elevation) of the Sierra Nevada. While there was some overlap between the deer crash and deer carcass hotspots, there were also differences. Crash hotspots occurred mostly in the southern portion of Caltrans District 10 around Mariposa and also in the center of Caltrans District 10 around Jamestown whereas carcass hotspots occur mostly in the northern portion of Caltrans District 10 around Jackson and also in the center around Jamestown. The differences in locations for the crash and carcass hotspots (mostly the crashes around Mariposa versus the carcasses around Jackson) are likely related to geographical differences in search and reporting effort for the crash data, the carcass data or both. None of the crash hotspots were located in Natural Landscape Blocks or Essential Connectivity Areas, but four out of the twelve carcass hotspots were located in an Essential Connectivity Area (around Pine Grove).

None of the crash hotspots had road sections where the economic threshold values for the implementation of the investigated mitigation measures were met. However, seven out of the twelve carcass hotspots did meet or exceed at least one of the thresholds. While the researchers strongly advise to use the cost-benefit analyses as a decision support tool they also urge users to recognize that these analyses are only one of the factors that may or should be considered in the decision making process. For example, human safety should perhaps not only be evaluated in dollar values and passive use values for wildlife are currently not included in the cost-benefit analyses.

Should mule deer-vehicle collisions be mitigated in one or more of the crash or carcass hotspots, the researchers suggest large mammal fencing in association with large mammal underpasses. If larger structures can be built, e.g. overspan bridges, wildlife use is likely higher than with large mammal underpasses, but wildlife overpasses do not appear to be required based on the other species believed to be present in the area around the crash and carcass hotspots. Underpasses can be combined with stream crossings (preferably bottomless structures), with natural streambed and banks to continuing under the road and a minimum path width of 2-3 m for large terrestrial mammals including mule deer. The researchers recommend placing large boulders or tree trunks or root wads inside and adjacent to underpasses. This provides cover for smaller species groups including small mammals, reptiles and amphibians.

The researchers recommend large mammal wildlife fencing in association with underpasses. This is likely to result in higher use of the crossing structures by large mammals and much reduce at-grade crossing opportunities for the road length that is fenced. The longer the road section that is fenced, the less likely it is that animals that could or would use the underpass will walk to the fence end to cross at grade. While longer section of fencing are likely beneficial with regard to both human safety and the number of wildlife that cross the highway, there are several factors that may limit the presence and length of the wildlife fencing:

- Width of the right-of-way and the clear recovery zones
- Access roads, including driveways (though gaps in the fence can be mitigated with wildlife (cattle) guards or electric mats).
- Concerns about landscape aesthetics (adjacent landowners, drivers, some road sections are designated State Scenic Highways)

Since hotspots typically vary with regard to the specific road and right-of-way configuration, surrounding landscape, and land ownership, local conditions can have a strong influence what the opportunities for mitigation are at each hotspot.

1. INTRODUCTION

1.1. Background

Wildlife-vehicle collisions affect human safety, property (damage) and wildlife. The total number of large mammal–vehicle collisions has been estimated at one to two million in the United States annually (Conover et al. 1995, Huijser et al. 2009). These collisions were estimated to cause 211 human fatalities, 29 000 human injuries, and over one billion US dollars in property damage annually (Conover et al. 1995). More recent estimates that include costs associated with human injuries and human fatalities estimate the yearly costs associated with wildlife-vehicle collisions between 6-12 billion US dollars (Huijser et al. 2009). In most cases, the animals die immediately or shortly after the collision (Allen & McCullough 1976). In some cases, it is not just the individual animals that suffer. Road mortality may also affect some species on the population level (e.g., van der Zee et al. 1992, Huijser & Bergers 2000), and some species may even be faced with a serious reduction in population survival probability as a result of road mortality, habitat fragmentation, and other negative effects associated with roads and traffic (Proctor 2003, Huijser et al. 2007). In addition, some species also represent a monetary value that is lost once an individual animal dies (Romin & Bissonette 1996, Conover 1997).

The highways in Caltrans District 10 in Central California are important for local, state and interstate travel. However, the frequency of wildlife-vehicle collisions, specifically with mule deer (or black-tailed deer) (*Odocoileus hemionus*), is considered high or high enough by Caltrans to explore procedures and tools to identify and prioritize wildlife-vehicle collision hotspot analyses. The procedures and tools should help standardize the future analyses of wildlife-vehicle collision data in District 10 and beyond. Once wildlife-vehicle collision hotspots have been identified and prioritized potential future mitigation measures need to be formulated. These mitigation measures should be aimed at reducing wildlife-vehicle collisions, particularly with mule deer and other large mammals, and at providing safe crossing opportunities for a wide range of wildlife species.

1.2. Project Goals and Objectives

This project focuses on providing a strategy for the potential future implementation of mitigation measures for wildlife along highways. The general goals of the potential future mitigation measures are to:

- Reduce direct wildlife mortality of large mammal species along highways in Caltrans District 10 and elsewhere in California.
- Maintain or improve habitat connectivity for a wide variety of wildlife species, specifically amphibian, reptile, and mammal species, across highways in Caltrans District 10 and elsewhere in California.

This proposed project includes data from highways in Caltrans District 10 only (Figure 1). The total length of these highways is estimated at about 1,836 mi (total length of the highways).

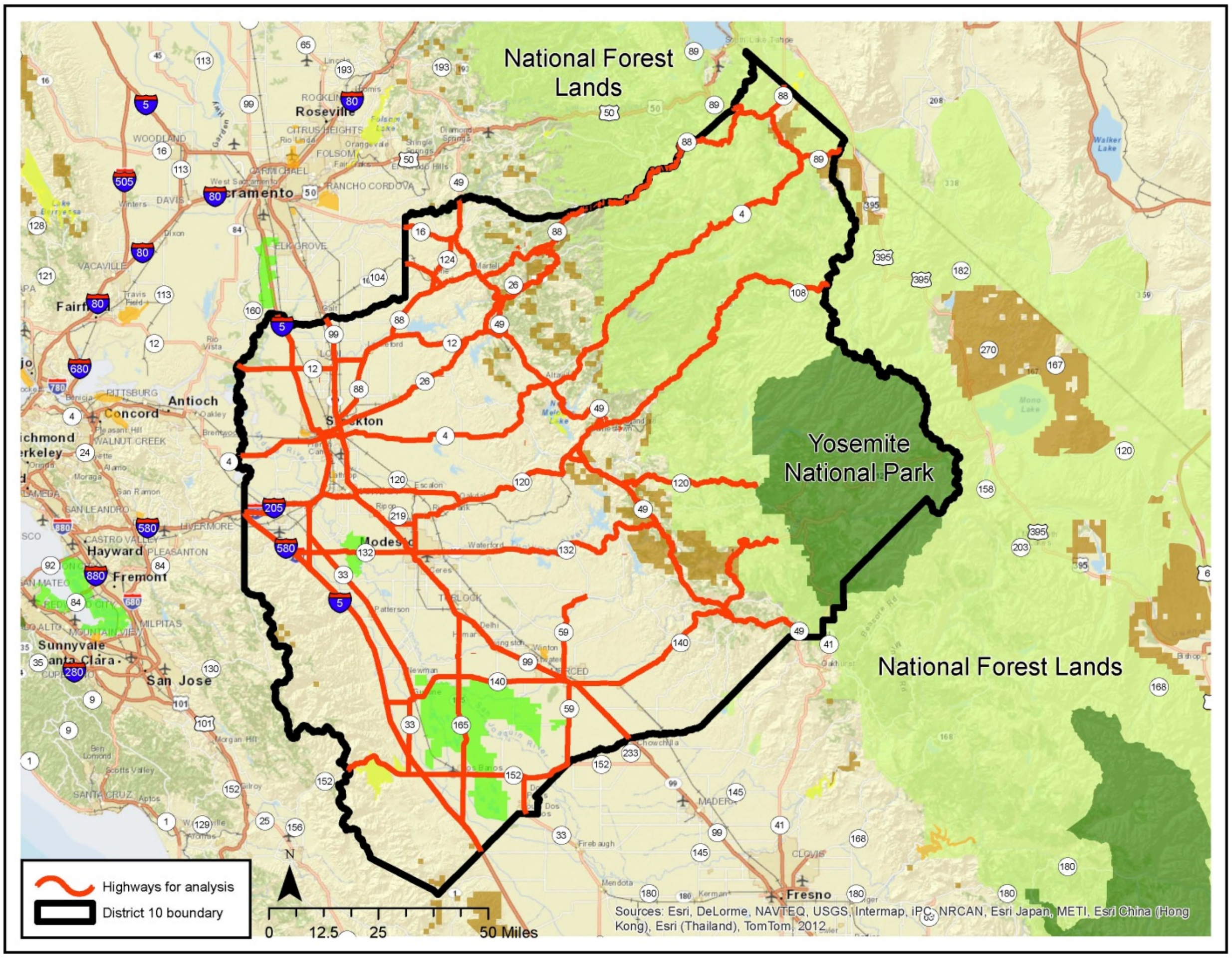

Figure 1: The highways included in the proposed project in Caltrans District 10, California, USA.

The specific objectives for this project are:

1. Obtain existing wildlife-vehicle collision and wildlife road mortality data for selected highways in Caltrans District 10.
2. Identify hotspots based on the crash data and the carcass removal data. Hotspots are highway segments that have a concentraton of wildlife-vehicle collisions.
3. Prioritize the hotspots based on three types of parameters:
    a. Human safety;
    b. Nature conservation, and;
    c. Economic parameters.
4. Document the identification and prioritization process in a step-by-step manner as a reference for potential future analyses in District 10 or elsewhere.
5. Develop a methodology for appropriate mitigation measures and suggest mitigation measures for a selection of the hotspots (e.g. top 5 or top 10 hotspots in District 10).

2. STEPWISE APPROACH: DEFINE PROBLEM AND DECIDE ON APPROACH

2.1. Define the Problem

In North America wildlife mitigation measures along highways are often primarily based on wildlife-vehicle collision data and a desire to improve safety for humans. Along most roads in North America there are two types of wildlife-vehicle collision data:

- Crash data: These data are typically collected by law enforcement personnel. For a crash to be entered into the database there is often a threshold (e.g. minimum estimated vehicle repair cost at least US $1,000) and/or human injuries and human fatalities (Huijser et al., 2007).
- Carcass data: These data are typically collected by road maintenance crews when they remove carcasses of large mammals that are on the road or that are very visible from the road in the right-of-way and that are an immediate safety hazard or a distraction to drivers (Huijser et al., 2007). Note that carcass data are sometimes also collected by personnel from natural resource management agencies, researchers, or the general public (Paul, 2007).

Both types of data tend to relate to large mammals only; medium sized and small sized mammals and other species groups such as amphibians, reptiles and birds are usually inconsistently recorded or not recorded at all (Huijser et al., 2007). Furthermore, crash data typically represent only a fraction (14-50%) of the carcass data, even if both data sets relate to large mammals only (Tardif and Associates Inc,. 2003; Riley & Marcoux, 2006; Donaldson & Lafon, 2008). Finally the carcass data are far from complete as well; animals that are not very visible from the road in the right-of-way may not be removed and do not get recorded. Wounded animals that make it beyond the right-of-way fence before they die are also usually not recorded at all.
If only wildlife-vehicle collision data are used to identify and prioritize locations along highways that that may require wildlife mitigation measures, then the concern is typically primarily with human safety and reducing collisions with large mammals, specifically the most common ungulates such as white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*) and moose (*Alces alces*).

If the concern is with direct road mortality for species or species groups other than common large mammals then data sources other than crash data and carcass removal data may be required. A specific road-kill monitoring program may have to be developed. Depending on the exact goals of the project and the associated requirements such data may be collected by personnel from natural resource management agencies, researchers or the public.

While there is much emphasis on mitigating for wildlife-vehicle collisions in North America, crashes, dead animals, and associated costs and risks to humans are not the only reason mitigation for wildlife along highways may be considered. The authors of this report distinguish five different categories of effects of roads and traffic on wildlife (Figure 2):

- Habitat loss: e.g., the paved road surface, heavily altered environment through the road bed with non-native substrate, and seeded species and mowing in the clear zone.
- Direct wildlife road mortality as a result of collisions with vehicles.
- Barrier to wildlife movements: e.g., animals do not cross the road as often as they would have crossed natural terrain and only a portion of the crossing attempts is successful.
- Decrease in habitat quality in a zone adjacent to the road: e.g., noise and light disturbance, air and water pollution, increased access to the areas adjacent to the highways for humans.
- Right-of-way habitat and corridor: Depending on the surrounding landscape the right-of-way can promote the spread of non-native or invasive species (surrounding landscape largely natural or semi-natural) or it can be a refugium for native species (surrounding landscape heavily impacted by humans).

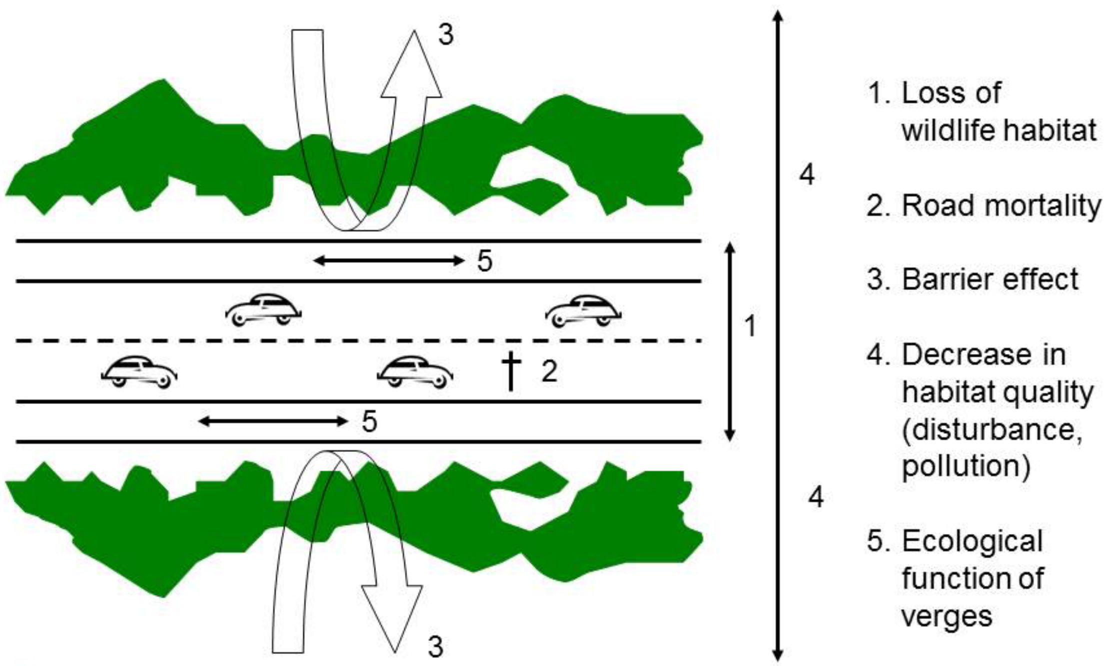

Figure 2: The effects of roads and traffic on wildlife.

If mitigation is required for habitat loss, barrier effects, a decrease in habitat quality in a zone adjacent to the road, or the ecological functioning of right-of-ways, other types of data are needed than wildlife-vehicle collision data. Examples of such data are data on the quantity and quality of the habitat impacted, animal movement data, data on noise or chemical pollutants, and the presence of non-native invasive species. Note that wildlife-vehicle collision hotspots are not necessarily the locations where animals cross the road most frequently or where safe crossing opportunities would have the greatest benefit to the long-term population viability for selected species.

2.2. Decide on the Approach: Avoidance, Mitigation, or Compensation

While mitigation (reducing the severity of an impact) is common, avoidance is better and should generally be considered first (Cuperus et al., 1999). For example, the negative effects of roads and traffic may be avoided if a road is not constructed, or the most severe negative effects may be avoided by re-routing away from the most sensitive areas (Figure 3). If the effects cannot be avoided, mitigation is a logical second step. Mitigation is typically done in the road-effect zone (Figure 3) and may include measures aimed at reducing wildlife-vehicle collisions and reducing the barrier effect (e.g., through providing for safe wildlife crossing opportunities) (Huijser et al., 2008; Clevenger & Huijser, 2011). However, mitigation may not always be possible or the mitigation may not be sufficient. Then a third approach may be considered: compensation or mitigation off-site. Compensation may include increasing the size existing habitat patches, creating new habitat patches or improving the connectivity between the habitat patches that would allow for larger, more connected, and more viable network populations. Finally, in some situations a combination of avoidance, mitigation, and compensation may be implemented.

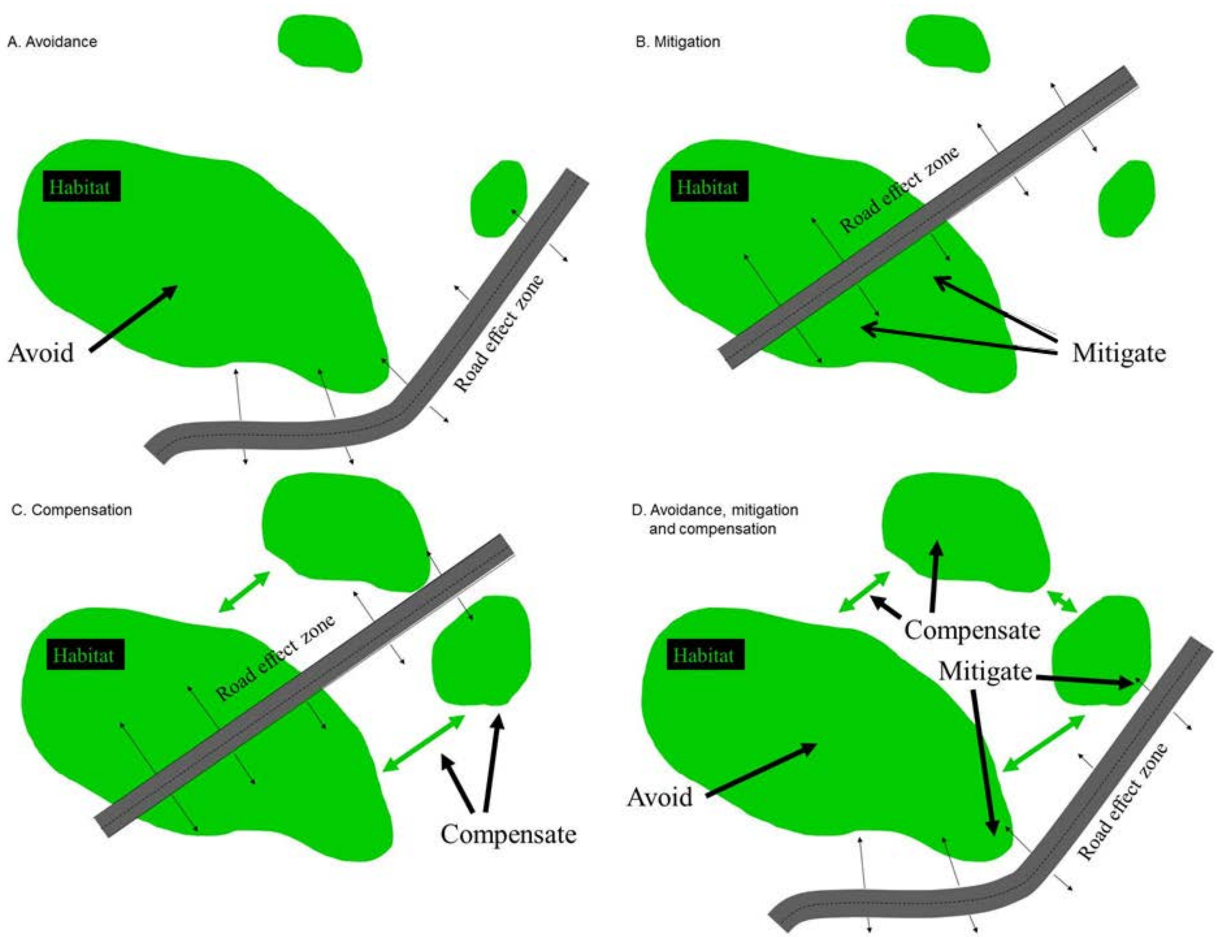

Figure 3: A three step approach: A. Avoidance, B. Mitigation, C. Compensation, D. Combination of avoidance, mitigation and compensation.

3. STEPWISE APPROACH: IDENTIFY WILDLIFE-VEHICLE COLLISION HOTSPOTS USING DATA FROM CALTRANS DISTRICT 10 AS AN EXAMPLE

3.1. Project Specific Approach

For the current project the problem, as defined by Caltrans, is the high number of collisions with large mammals, particularly with mule deer (or black-tailed deer) (*Odocoileus hemionus*) and the associated risks for human safety. This chapter describes the procedures used to identify wildlife-vehicle collision hotspots. The procedures should help standardize the future analyses of wildlife-vehicle collision data in District 10 and beyond. Once wildlife-vehicle collision hotspots have been identified (this chapter) they are prioritized based on human safety, nature conservation, and economic parameters (Chapter 4). Specific mitigation measures are suggested in Chapter 5.

The hotspot identification process results in hotspots that based on human safety data only. This is important to recognize as an alternative process that would identify hotspots based on – for example - nature conservation may result in the identification of very different road segments as this may include different species and habitat. This is not a problem, but it is important to recognize that the “departure point” for the identification and prioritization process for this project is to identify wildlife-vehicle collision hotspots based on human safety rather than anything else.

3.2. Identify Wildlife-Vehicle Collision Data Sources and Select Data

The researchers used two datasets to identify wildlife-vehicle collision hotspots:

1. Wildlife-vehicle crash data recorded by California Highway Patrol (TASAS)
2. Carcass removal data recorded by Caltrans maintenance personnel. Note: the Integrated Maintenance and Management system (IMMS) contains the same records as the carcass removal data. Therefore the IMMS data will not be used for this project.

The following records were selected from the two datasets:

- Observations from 1 January 2000 through 31 December 2010 (11 years). The time period was the exact same for the two datasets so that the wildlife-vehicle collision hotspots can be compared between the two datasets. Note that only selecting data for the last one or two years may better indicate where wildlife-vehicle collisions occur currently. However, a spatial pattern that is based on one or only a few years may not be very robust and may misidentify true collision hotspots. On the other hand, if several decades’ worth of data is used, the hotspot analyses may identify road sections where collisions were concentrated in the past rather than where they occur now. This not only relates to the changes to the road or in the right-of-way, but also, perhaps even especially, to changes in the surrounding landscape. Though there is no general rule on this matter, around 10 years’ worth of data appears to be a good balance between being able to identify current or recent hotspots vs. having a robust dataset to minimize the likelihood of misidentifying hotspots.

- For the wildlife-vehicle crash dataset:
  - Only records that related to deer were selected (Party type = X = animal-deer) as other wildlife species were not or less consistently reported. Note that if the focus of the project is on less common species carcass removal data may not be very helpful as the number of carcasses is likely very low and the reporting is less consistent (e.g. because the species may be too small to be consistently seems and removed, other organizations or individuals may remove the animals (legally or illegally) which means the carcasses may have disappeared before road maintenance crews have an opportunity to remove and record the carcasses).
- For the carcass removal data set:
  - Only records that related to deer were selected as other wildlife species were not or less consistently reported.
  - If age and gender of the animal was not indicated, but if there was nothing to suggest it was not a deer record was not deleted.
  - Data quality control: Records with an observation year that was clearly wrong (wrong data entry) were deleted (n=2).
  - Data quality control: Records with no observation date were deleted (n=7).
  - Data quality control: Records that had a clearly wrong observation day were changed (e.g. 31 November was changed to 30 November) (n=3).

3.3. Evaluate Search and Reporting Effort

For the data analyses described in the following sections (trend over time, hotspot analyses) the researchers assumed that the search and reporting effort between the different years and road sections was consistent. If the search and reporting effort varies between years, it may not be appropriate to use the data to investigate if there are changes (increase or decrease) in the number of wildlife-vehicle collisions over the years. If the search and reporting effort varies between road sections, it may not be appropriate to use the data to investigate if there are concentrations of wildlife-vehicle collisions along certain road sections.

While consistent search and reporting effort is essential for analyzing temporal and spatial trends it is not assumed that every wildlife-vehicle collision (or deer-vehicle collision in this particular case) ends up in the crash database or the carcass removal database. Consistent search and reporting effort can relate to only a fraction of the actual number of collisions. What matters is that a crash or carcass has similar likelihood of being recorded in different years (for temporal analyses to investigate if the deer-vehicle collisions may have increased or decreased over the years) and similar likelihood of being recorded on different road sections (for spatial analyses to investigate if there are concentrations of deer-vehicle collisions on certain road sections (“hotspots”)).

The search and reporting effort for crash data is typically lower than for carcass removal data (Tardif and Associates Inc,. 2003; Riley & Marcoux, 2006; Donaldson & Lafon, 2008). For a crash to be included in the crash database in the state of California there must be human injuries or human fatalities associated with the crash or the estimated damage to property has to be US$ 500 at a minimum (Caltrans, 2013a). However, depending on the severity of a reported crash, other tasks, and the distance to the crash site there is not always sufficient law enforcement personnel available to respond and record the crash. For a carcass to be included in the carcass removal database Caltrans personnel must have gone out and removed a carcass. The presence of a carcass is reported to Caltrans maintenance crews in the following manners (Personal communication Caltrans maintenance personnel in Pinegrove and Jamestown, Caltrans District 10):

- Telephone call by the public.
- Reports from Caltrans personnel commuting to and from work.
- Requests from law enforcement personnel/dispatch.
- Observations by Caltrans maintenance personnel on route to or from an assigned task.
- Observations by Caltrans maintenance personnel conducting weekly road inspections.

The search and reporting effort for large mammal (i.e. deer) carcasses is believed to be similar for the different road maintenance crews in District 10 (Personal communication Caltrans maintenance personnel in Pinegrove and Jamestown, Caltrans District 10).

3.4. Trend Wildlife-Vehicle Collisions

The total number of reported deer crashes and deer carcasses was tallied per calendar year (Figures 4 and 5). The number of reported deer crashes appeared relatively stable, perhaps with a decreasing trend since 2005. The number of reported deer carcasses appeared to be far more variable than the deer crash data. Overall, the reported crash data were 24.8% of the reported carcass data.

The crash and carcass data suggest that the search and reporting effort has not been consistent for the crash data, the carcass data, or both, at least not between years. Despite the fact that the reported deer crash data were only 24.8% of the reported deer carcasses, the researchers think that crash data are more likely to have consistent search and reporting effort than carcass removal data. On the other hand, if one is more interested in a total estimate of the number of deer-vehicle collisions rather than a consistent search and reporting effort to identify deer-vehicle collision hotspots, carcass data are less of an underestimate than crash data.

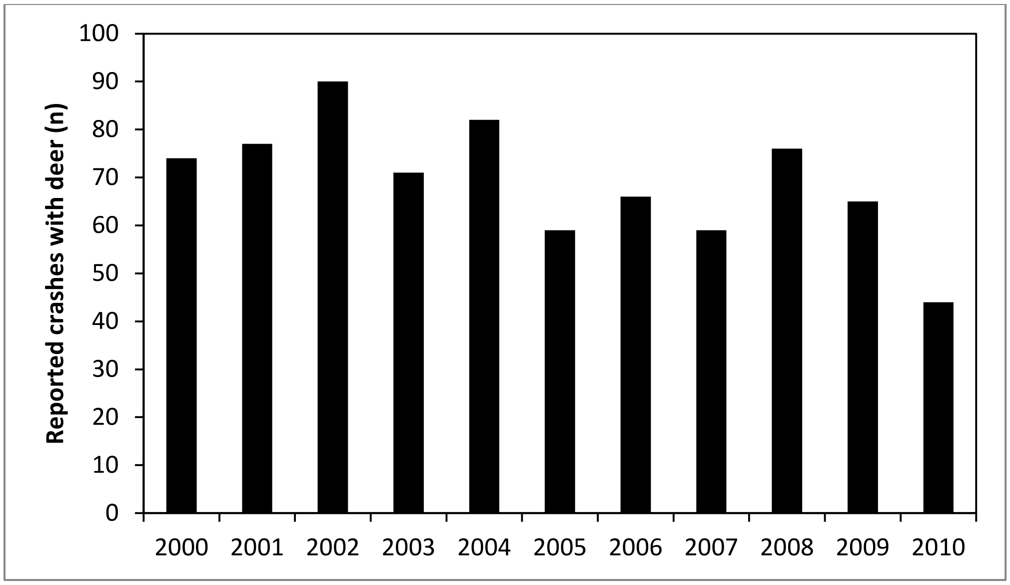

Figure 4: The number of reported crashes with deer in Caltrans District 10 per year.

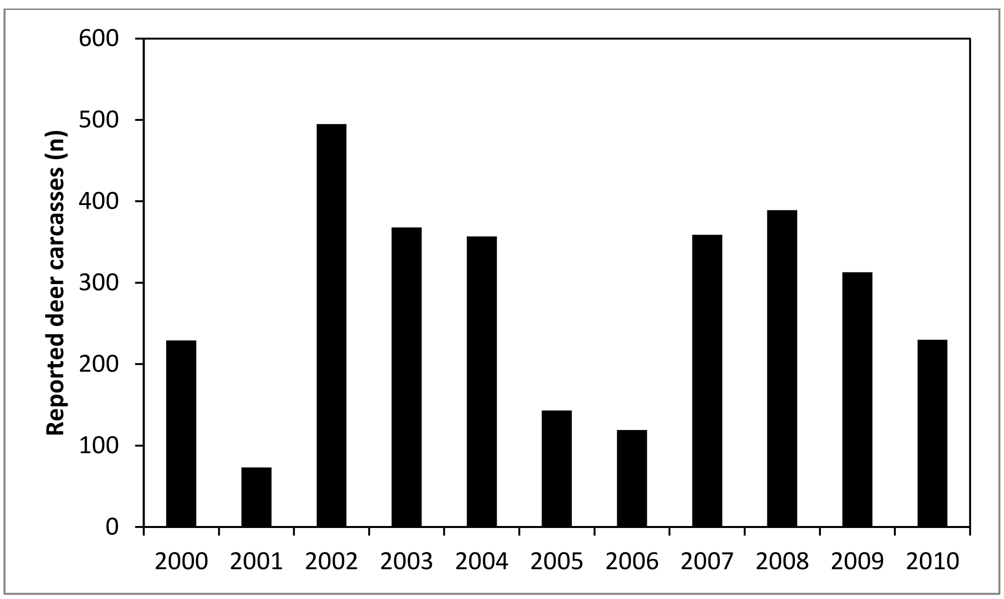

Figure 5: The number of reported deer carcasses in Caltrans District 10 per year.

3.5. Hotspot Analyses

The researchers conducted two separate analyses to identify wildlife-vehicle collision hotspots along the roads in Caltrans District 10: one based on crash data and one based on carcass removal data. The procedure for the two analyses was the same and consisted of the following steps:

Step 1: Integrate the crash and carcass locations in a spatial database. For Caltrans District 10 the location for the crash and carcass data is based on the county, the highway number, and the nearest 0.1 mile post. Note that different counties may have the same 0.1 mile post numbers for the same highway. The location of the 0.1 mi posts (based on county, highway number and 0.1 mi post) was already available in ArcGIS format. This made it relatively simple to integrate the crash and carcass data in the spatial database.

Step 2: Conduct a Kernel density (ArcGIS Release 9.3) analysis for point features. The analyses included all crash data or all carcass removal data from all roads in District 10. This means that, at least in theory, all hotspots can be located on one of the roads or road sections in District 10, and that other road sections may have no identified hotspots. For the Kernel density analyses the researchers divided the study area into a grid with a cell size of 82 x 82 ft (25 x 25 m). The relatively small cell size results in a relatively fine or smooth map. The locations of the crashes and carcasses are considered points and the Kernel density analysis calculates the density of crashes or carcasses in a neighborhood around each cell. Points that are close are weighted more than points that are further away. Consistent with Gomes et al. (2009) we set the search radius at 500 meters (m). On a straight road this basically means that crashes or carcasses that are up to about 0.3 mi (500 m) away are included in the density analyses for each cell. For the Kernel density analyses we first calculated the area for the 95% Kernel polygon (Table 1) (see Bingham & Noon (1997) for a detailed description of the procedure). This means that the researchers omitted the 5% of cells that had the least spatial concentration of crashes or carcasses; these cells did not have any effect on the hotspot analyses. Secondly the researchers calculated the area covered within nine additional Kernel isopleths (range 5%-85%) (Table 1). The area covered within the 95% Kernel isopleth was set at 100% and the areas covered within the additional nine isopleths were expressed as a percentage of the area for the 95% Kernel isopleth (Table 1).

Table 1: The Kernel isopleths and the area covered within these isopleths.

	Crash data		Carcass data	
Isopleth	Area (m^2)	Area %	Area (m^2)	Area %
95	225553500	100.00	184986000	100.00
85	40626000	18.01	42544800	23.00
75	14894100	6.60	18312300	9.90
65	6352200	2.82	12096000	6.54
55	1950300	0.86	7812900	4.22
45	754200	0.33	3452400	1.87
35	563400	0.25	1840500	0.99
25	273600	0.12	374400	0.20
15	245700	0.11	245700	0.13
5	126000	0.06	116100	0.06

Step 3: Conduct an exponential regression analysis ($y=ae^{bx}$). The ten Kernel isopleths (5%-95%) represented the value of the independent variable (x) on the horizontal axis, and the area covered

within each of the Kernel isopleths expressed as a percentage of the area covered within the 95% isopleth represented the dependent variable (y) on the vertical axis (Figure 6 and 7). If the distribution of the cells with the density of the crashes or carcasses within the 95% AK isopleth would be perfectly uniform, then the regression of x on y would be a straight line through the origin with a slope of exactly 1; for each unit increase of the Kernel isopleths, the area within these isopleths also increases one unit. Should there be a concentration of crashes or carcasses, then the regression of x on y will fall below the line y=x ; i.e., *b* will be less than 1. We conducted an exponential regression analysis ($y=ae^{bx}$). The estimates for *a* and *b* for the crash and carcass data are shown in (Figure 6 and 7).

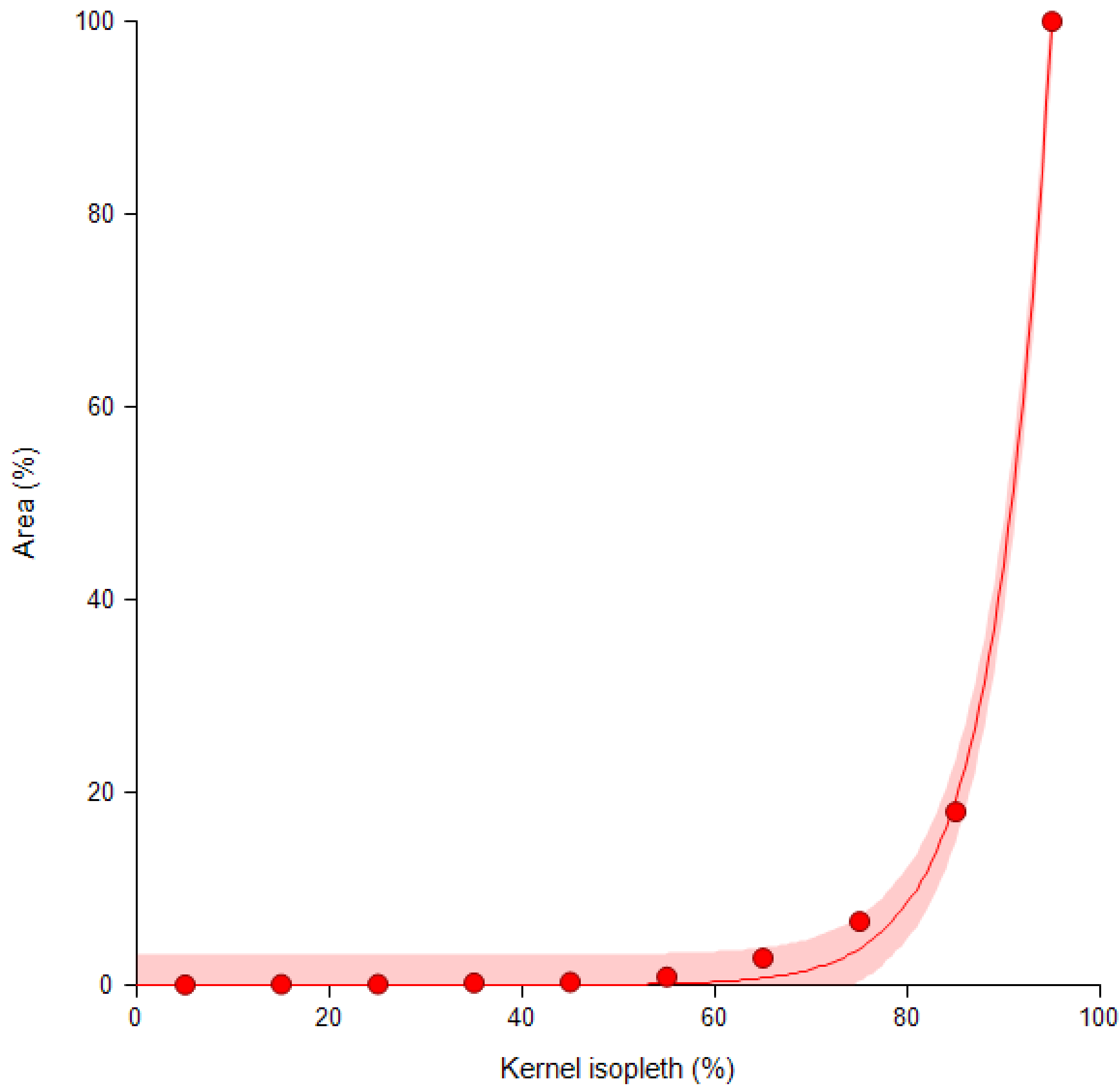

Figure 6: The Kernel isopleths (x-axis) for the crash data and the area within the isopleths (y-axis)) expressed as a percentage of the area within the 95% isopleth. The function is $y = 0.00001*e^{0.16400*x}$. The shaded area around the function represents the upper and lower 95% prediction limit. Slope equals 1 at the 77.4% Kernel isopleth (3.3% of the total area within the 95% isopleth).

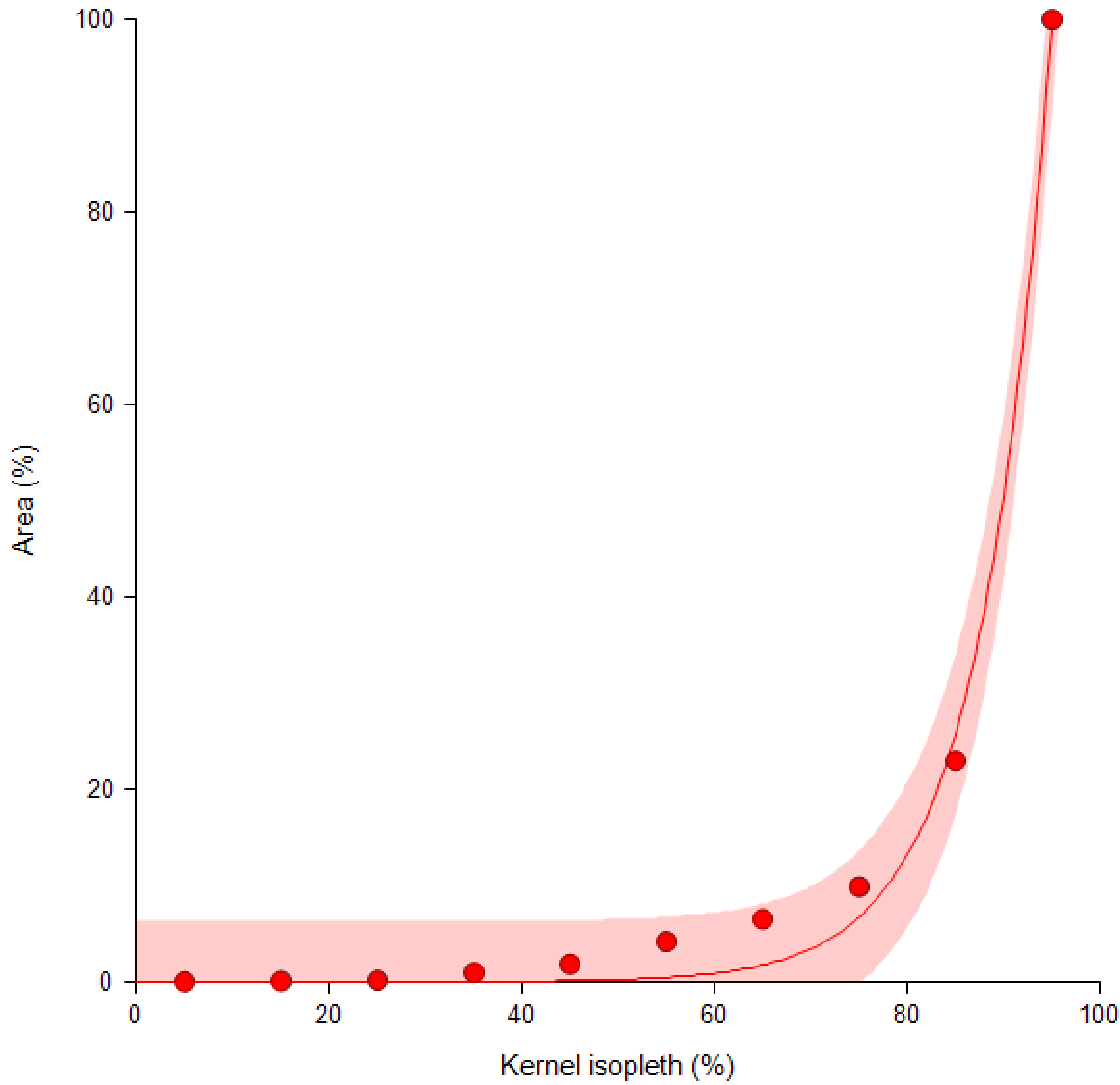

Figure 7: The Kernel isopleths (x-axis) for the carcass data and the area within the isopleths (y-axis)) expressed as a percentage of the area within the 95% isopleth. The function is $y = 0.00010*e^{0.13459*x}$. The shaded area around the function represents the upper and lower 95% prediction limit. Slope equals 1 at the 75.2% Kernel isopleth (2.5% of the total area within the 95% isopleth).

Step 4: Identify road sections with the cells that have the densest concentration of crashes or carcasses (see step 2 for description of the cells and how their values were calculated) up to where the crashes or carcasses are no longer concentrated (i.e. Kernel isopleth slope > 1). In our case these are the cells that have the densest crashes or carcasses up to 3.3% of the total area within the 95% isopleth (for crash data) or up to 2.5% of the total area within the 95% isopleth (for carcass data) (i.e. Kernel isopleth slope < 1) (Figure 8 and 9; Table 2).

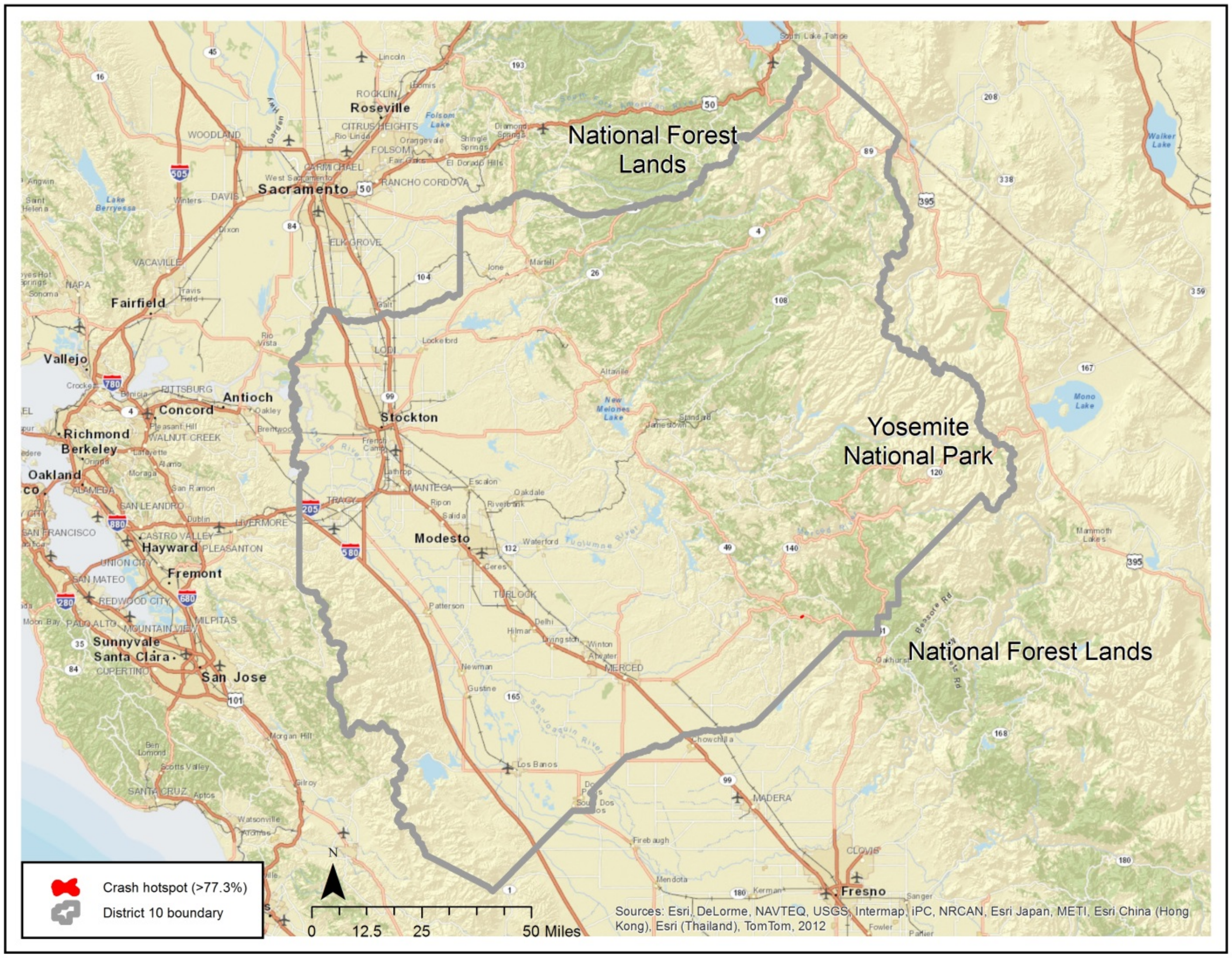

Figure 8: The road sections (in red, Kernel isopleth >77.3%) where the cells based on the crash data have a concentrated distribution (i.e. slope <1 in Figure 6).

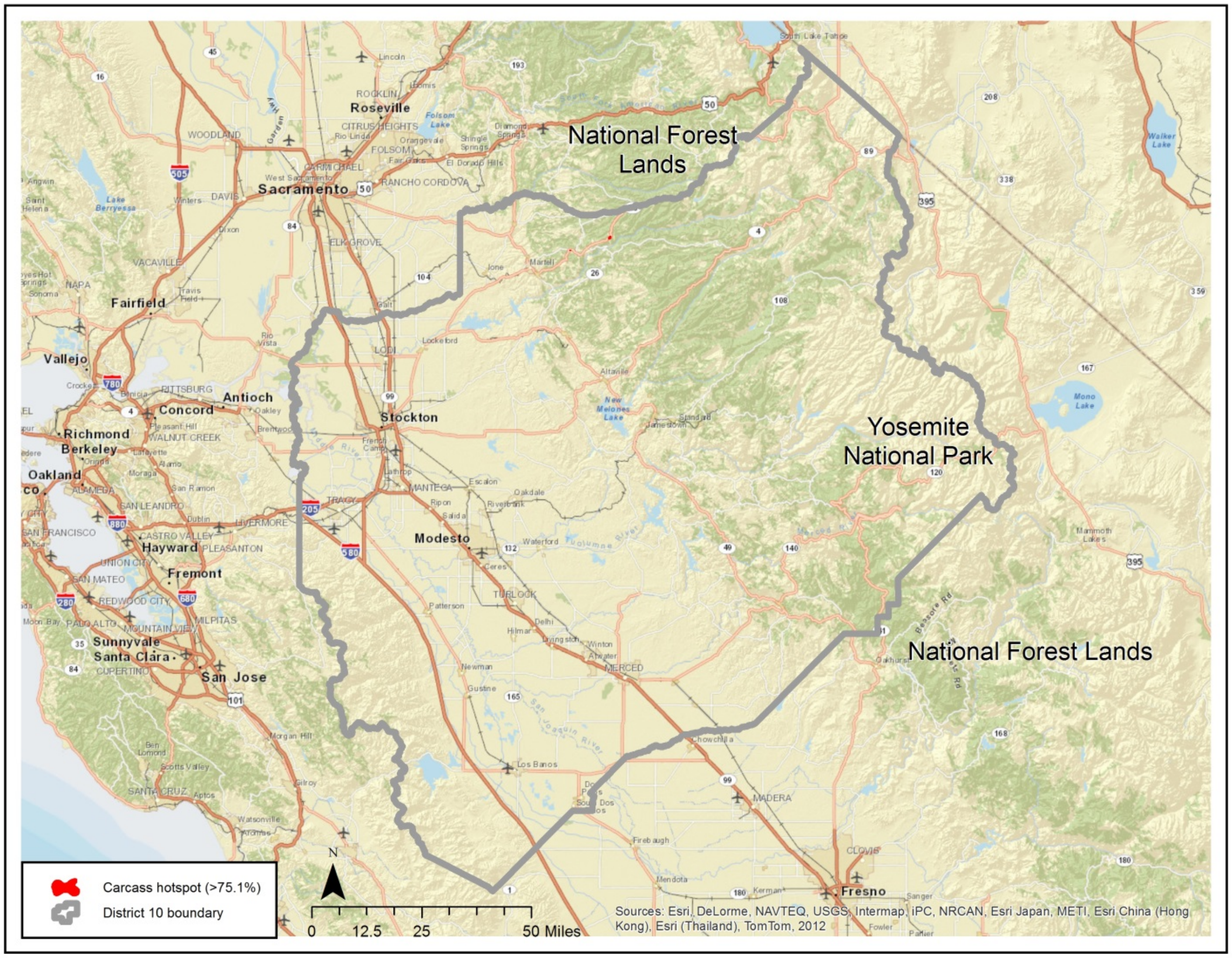

Figure 9: The road sections (in red, Kernel isopleth >75.1%) where the cells based on the crash data have a concentrated distribution (i.e. slope <1 in Figure 7).

Table 2: The start and end points for the road sections where the cells based on crash and carcass data have a concentrated distribution (i.e. road sections in red in Figure 8 and 9).

Crash or carcass data	Start (county, Hwy #, mi post)	End (county, Hwy #, mi post)
Crash	MPA, 49, 12.2	MPA, 49, 12.9
Carcass	AMA, 88, 22.7	AMA, 88, 23.0
Carcass	AMA, 88, 31.6	AMA, 88, 32.4

Step 5: Identify additional road sections that may be considered for mitigation. While it is useful to identify road sections that have a concentrated distribution of crashes or carcasses, there may be a desire to identify additional road sections that do not have a concentration that deviates from a uniform distribution, but that still have a relatively high concentration of crashes or carcasses. For this purpose the researchers considered road sections with no crashes or carcasses and road sections that fell into the two lowest density categories (50-100%; Table 3) (provided that the density is greater than 0) to be “background”. Road sections that had higher densities (“top 50%”) were considered a “hotspot” (i.e. yellow, orange or red in Figure 10 and 11).

Table 3: The categories used for maps with the hotspots based on the crash and carcass data (Figure 10 and 11).

	Density (n / square mile)		
Percentile categories	Crash data	Carcass data	Description
n/a	0	0	Further than 500 m from nearest crash or carcass
75-100%	0.1-2.45	0.1-8.30	The 25% of the cells with the lowest density (provided that the density is greater than 0)
50-74.9%	2.46-12.25	8.31-41.54	The next 25% of the cells with the lowest density (provided that the density is greater than 0)
25-49.9%	12.26-24.50	41.55-83.09	The next 25% of the cells with the lowest density (provided that the density is greater than 0)
5-24.9%	24.51-36.75	83.10-124.63	The next 20% of the cells with the lowest density (provided that the density is greater than 0)
<5%	36.76-49.00	124.64-166.18	The 5% of cells with the highest density (provided that the density is greater than 0)

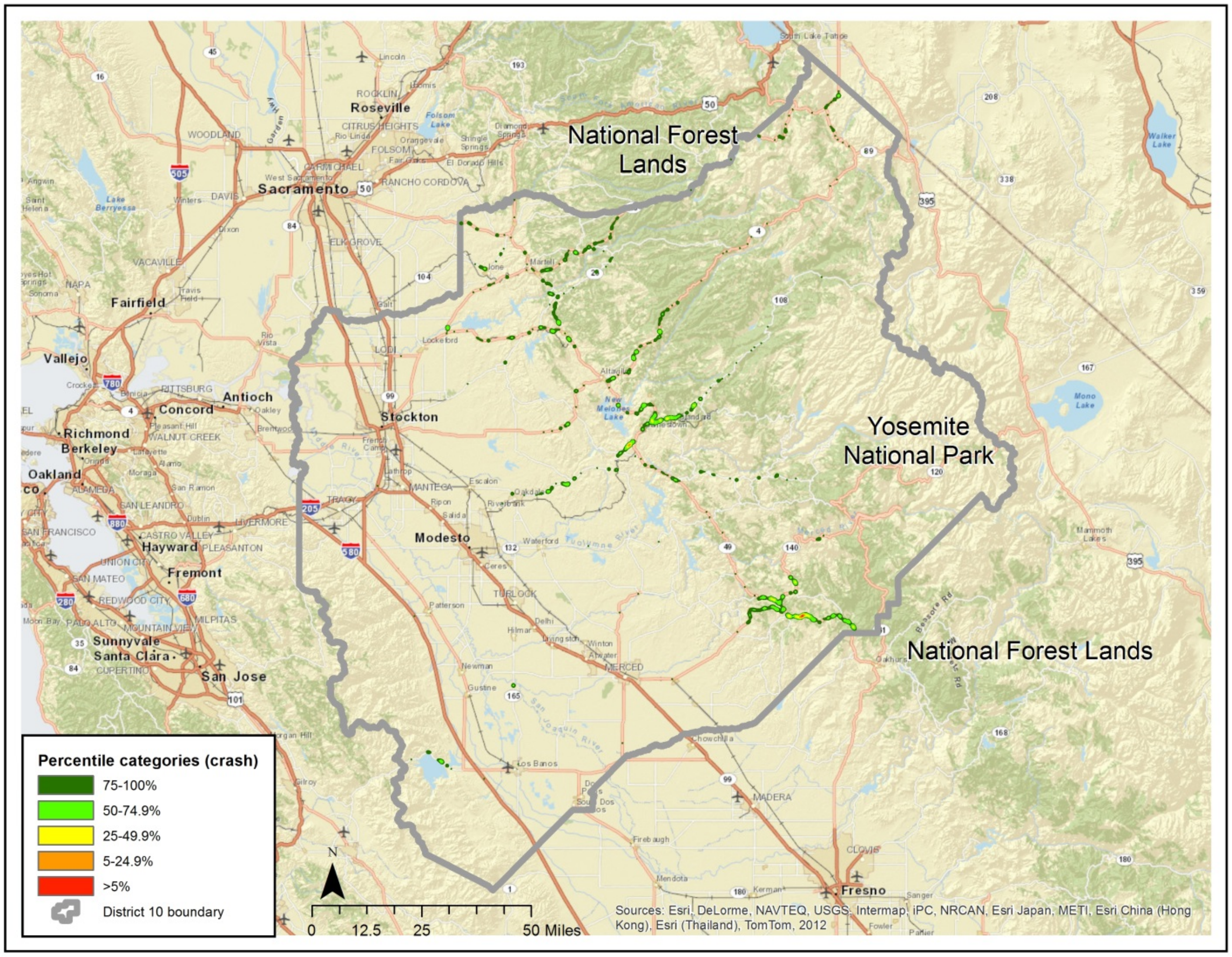

Figure 10: The hotspots based on crash data for the highways in Caltrans District 10.

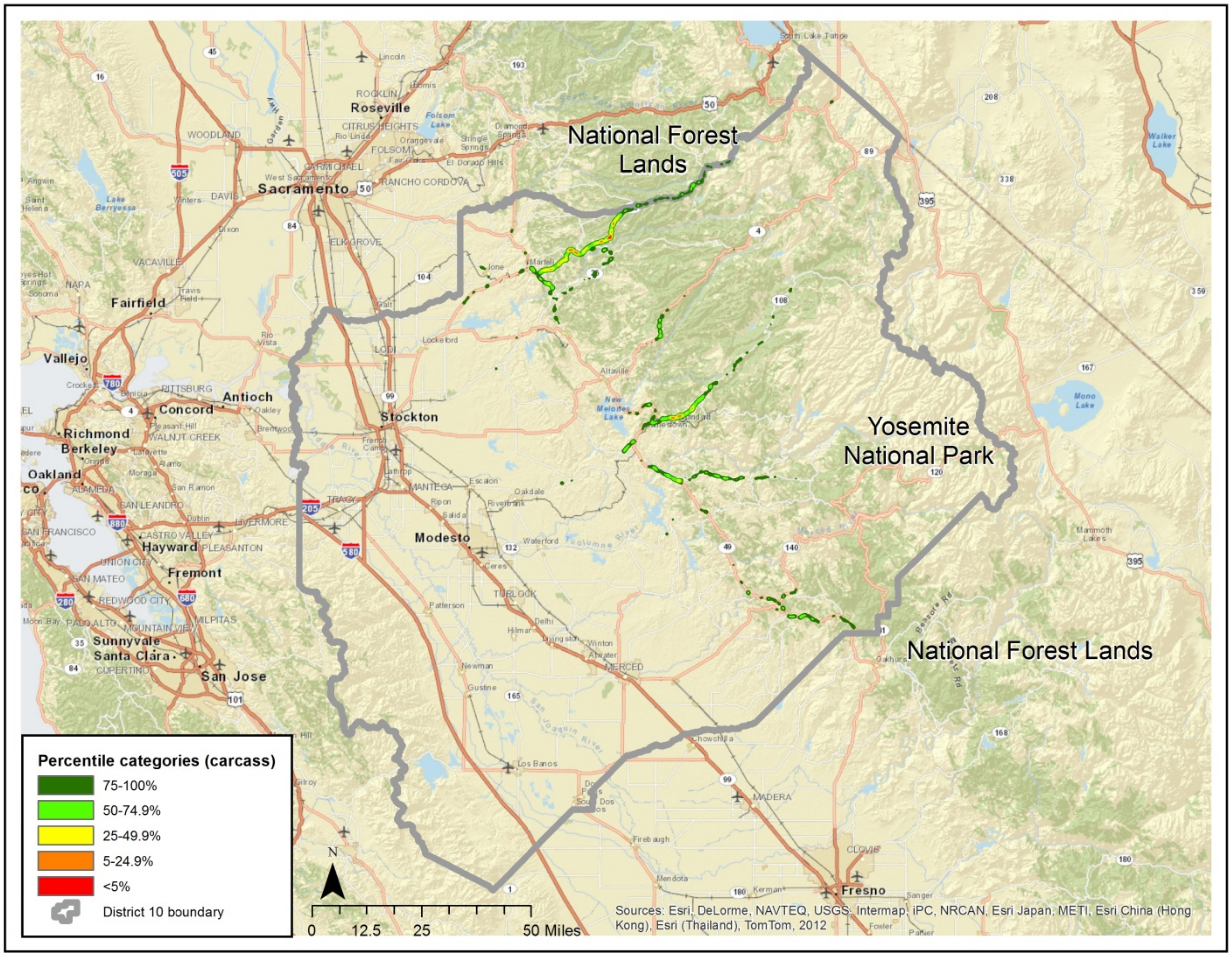

Figure 11: The hotspots based on carcass removal data for the highways in Caltrans District 10.

The exact location of the crash and carcass hotspots is listed in Tables 4 and 5. These tables also show where the orange or red percentile categories are within the hotspot; these are the “worst” road sections within the hotspots.

Table 4: The hotspots based on the crash data and the 0.1 mi markers where the percentile categories (see Figure 10) change. CAL = Calaveras, MPA = Mariposa, TUO = Tuolumne.

ID	Hwy	County	Mi post	Combination ID	Transition percentile categories
Crash 1	108	TUO	0.8	108TUO0.8	light green-yellow
Crash 1	108	TUO	1.2	108TUO1.2	yellow-orange
Crash 1	108	TUO	1.8	108TUO1.8	orange-yellow
Crash 1	108	TUO	2.1	108TUO2.1	yellow-light green
Crash 2	108	TUO	3.5	108TUO3.5	light green-yellow
Crash 2	108	TUO	3.6	108TUO3.6	yellow-light green
Crash 3	108	TUO	4.3	108TUO4.3	light green-yellow
Crash 3	108	TUO	4.6	108TUO4.6	yellow-light green
Crash 4	108	TUO	5.6	108TUO5.6	light green-yellow
Crash 4	108	TUO	6.3	108TUO6.3	yellow-light green
Crash 5	108	TUO	6.6	108TUO6.6	light green-yellow
Crash 5	108	TUO	6.8	108TUO6.8	yellow-light green
Crash 6	108	TUO	11.7	108TUO11.7	light green-yellow
Crash 6	108	TUO	12.1	108TUO12.1	yellow-light green
Crash 7	140	MPA	28	140MPA28.0	light green-yellow
Crash 7	140	MPA	28.5	140MPA28.5	yellow-light green
Crash 8	4	CAL	34.9	4CAL34.9	light green-yellow
Crash 8	4	CAL	35.1	4CAL35.1	yellow-light green
Crash 9	49	MPA	1.1	49MPA1.1	light green-yellow
Crash 9	49	MPA	1.6	49MPA1.6	yellow-light green
Crash 10	49	MPA	10.8	49MPA10.8	light green-yellow
Crash 10	49	MPA	12	49MPA12.0	yellow-orange
Crash 10	49	MPA	12.3	49MPA12.3	orange-red
Crash 10	49	MPA	12.8	49MPA12.8	red-orange
Crash 10	49	MPA	13.2	49MPA13.2	orange-yellow
Crash 10	49	MPA	14	49MPA14.0	yellow-light green
Crash 11	49	MPA	14.8	49MPA14.8	light green-yellow
Crash 11	49	MPA	15.5	49MPA15.5	yellow-light green

Crash 12	49	MPA	18.1	49MPA18.1	light green-yellow
Crash 12	49	MPA	19.1	49MPA19.1	yellow-light green
Crash 13	49	TUO	15	49TUO15.0	light green-yellow
Crash 13	49	TUO	15.5	49TUO15.5	yellow-light green
Crash 14	49	TUO	20.1	49TUO20.1	light green-yellow
Crash 14	49	TUO	20.3	49TUO20.3	yellow-light green

Table 5: The hotspots based on the carcass data and the 0.1 mi markers where the percentile categories (see Figure 10) change. AMA = Amador, TUO = Tuolumne.

ID	Hwy	County	Mi post	Combination ID	Transition percentile categories
Carcass 1	49	AMA	1.1	49AMA1.1	light green-yellow
Carcass 1	49	AMA	1.5	49AMA1.5	yellow-light green
Carcass 2	88	AMA	15.2	88AMA15.2	light green-yellow
Carcass 2	88	AMA	16.8	88AMA16.8	yellow-orange
Carcass 2	88	AMA	17.4	88AMA17.4	orange-yellow
Carcass 2	88	AMA	18	88AMA18.0	yellow-light green
Carcass 3	88	AMA	18.6	88AMA18.6	light green-yellow
Carcass 3	88	AMA	19.1	88AMA19.1	yellow-orange
Carcass 3	88	AMA	19.4	88AMA19.4	orange-yellow
Carcass 3	88	AMA	20.4	88AMA20.4	yellow-orange
Carcass 3	88	AMA	20.6	88AMA20.6	orange-yellow
Carcass 3	88	AMA	21.6	88AMA21.6	yellow-light green
Carcass 4	88	AMA	22.2	88AMA22.2	light green-yellow
Carcass 4	88	AMA	22.4	88AMA22.4	yellow-orange
Carcass 4	88	AMA	24.5	88AMA24.5	orange-yellow
Carcass 4	88	AMA	24.8	88AMA24.8	yellow-light green
Carcass 5	88	AMA	25.7	88AMA25.7	light green-yellow
Carcass 5	88	AMA	27.2	88AMA27.2	yellow-light green
Carcass 6	88	AMA	28.5	88AMA28.5	light green-yellow
Carcass 6	88	AMA	29.6	88AMA29.6	yellow-orange
Carcass 6	88	AMA	30.3	88AMA30.3	orange-yellow
Carcass 6	88	AMA	31.2	88AMA31.2	yellow-orange
Carcass 6	88	AMA	31.6	88AMA31.6	orange-red
Carcass 6	88	AMA	32.2	88AMA32.2	red-orange
Carcass 6	88	AMA	32.7	88AMA32.7	orange-yellow
Carcass 6	88	AMA	32.9	88AMA32.9	yellow-orange
Carcass 6	88	AMA	33.5	88AMA33.5	orange-yellow
Carcass 6	88	AMA	34	88AMA34.0	yellow-light green
Carcass 7	88	AMA	34.3	88AMA34.3	light green-yellow
Carcass 7	88	AMA	34.5	88AMA34.5	yellow-orange
Carcass 7	88	AMA	35.2	88AMA35.2	orange-yellow
Carcass 7	88	AMA	36.8	88AMA36.8	yellow-light green

Carcass 8	108	TUO	6.4	108TUO6.4	light green-yellow
Carcass 8	108	TUO	6.6	108TUO6.6	yellow-orange
Carcass 8	108	TUO	7.4	108TUO7.4	orange-yellow
Carcass 8	108	TUO	7.8	108TUO7.8	yellow-orange
Carcass 8	108	TUO	8.8	108TUO8.8	orange-yellow
Carcass 8	108	TUO	9.2	108TUO9.2	yellow-light green
Carcass 9	108	TUO	9.7	108TUO9.7	light green-yellow
Carcass 9	108	TUO	10.1	108TUO10.1	yellow-light green
Carcass 10	108	TUO	10.7	108TUO10.7	light green-yellow
Carcass 10	108	TUO	11	108TUO11.0	yellow-orange
Carcass 10	108	TUO	11.3	108TUO11.3	orange-yellow
Carcass 10	108	TUO	12	108TUO12.0	yellow-light green
Carcass 11	108	TUO	13.5	108TUO13.5	light green-yellow
Carcass 11	108	TUO	13.7	108TUO13.7	yellow-light green
Carcass 12	120	TUO	23.8	120TUO23.8	light green-yellow
Carcass 12	120	TUO	24.4	120TUO24.4	yellow-light green

3.6. Ranking Hotspots Based on Human Safety

Tables 6 and 7 list the length of the crash and carcass hotspots and the number of reported deer crashes and deer carcasses in those hotspots. The number of deer crashes and deer carcasses in the hotspots were used to rank the hotspots for human safety. These rankings also also used later (Chapter 6) to finalize the prioritization of the hotspots.

Table 6: The length of the road segments with the crash hotspots, the number of deer crashes reported in those hotspots, and the ranking for human safety. The ranking was based first on the sum of deer crashes in the individual hotspots, and, in case of a tie, also on the average number of deer crashes in a hotspot per 0.1 mi.

Hotspot ID	Length (mi)	Sum deer crashes in hotspot (n)	Average deer crashes in hotspot (n/0.1 mi)	Ranking human safety
Crash 1	1.4	18	1.29	2
Crash 2	0.2	3	1.50	12
Crash 3	0.4	6	1.50	8
Crash 4	0.8	9	1.13	5
Crash 5	0.3	4	1.33	11
Crash 6	0.5	5	1.00	10
Crash 7	0.6	8	1.33	6*
Crash 8	0.3	5	1.67	9
Crash 9	0.6	7	1.17	7
Crash 10	3.3	50	1.52	1
Crash 11	0.8	10	1.25	4
Crash 12	1.1	14	1.27	3
Crash 13	0.6	8	1.33	6*
Crash 14	0.1	3	3.00	13

***= tie**

Table 7: The length of the road segments with the carcass hotspots, the number of deer carcasses reported in those hotspots, and the ranking for human safety. The ranking was based first on the sum of deer carcasses the individual hotspots, and, in case of a tie, also on the average number of deer carcasses in a hotspot per 0.1 mi.

Hotspot ID	Length (mi)	Sum deer carcasses in hotspot (n)	Average deer carcasses in hotspot (n/0.1 mi)	Ranking human safety
Carcass 1	0.5	22	4.40	10
Carcass 2	2.9	120	4.14	5
Carcass 3	3.1	121	3.90	4
Carcass 4	2.7	141	5.22	3
Carcass 5	1.6	61	3.81	7
Carcass 6	5.6	259	4.63	1
Carcass 7	2.6	111	4.27	6
Carcass 8	2.9	143	4.93	2
Carcass 9	0.5	17	3.40	11
Carcass 10	1.4	58	4.14	8
Carcass 11	0.3	8	2.67	12
Carcass 12	0.7	27	3.86	9

3.7. Detailed Maps of the Crash and Carcass Hotspots

Figures 12 and 13 show an overview of the locations of the crash hotspots and figure 14 shows an overview of the locations of the carcass hotspots. Figures 15-23 show detailed maps of the carcass hotspots and figures 24-26 show detailed maps of the carcass hotspots.

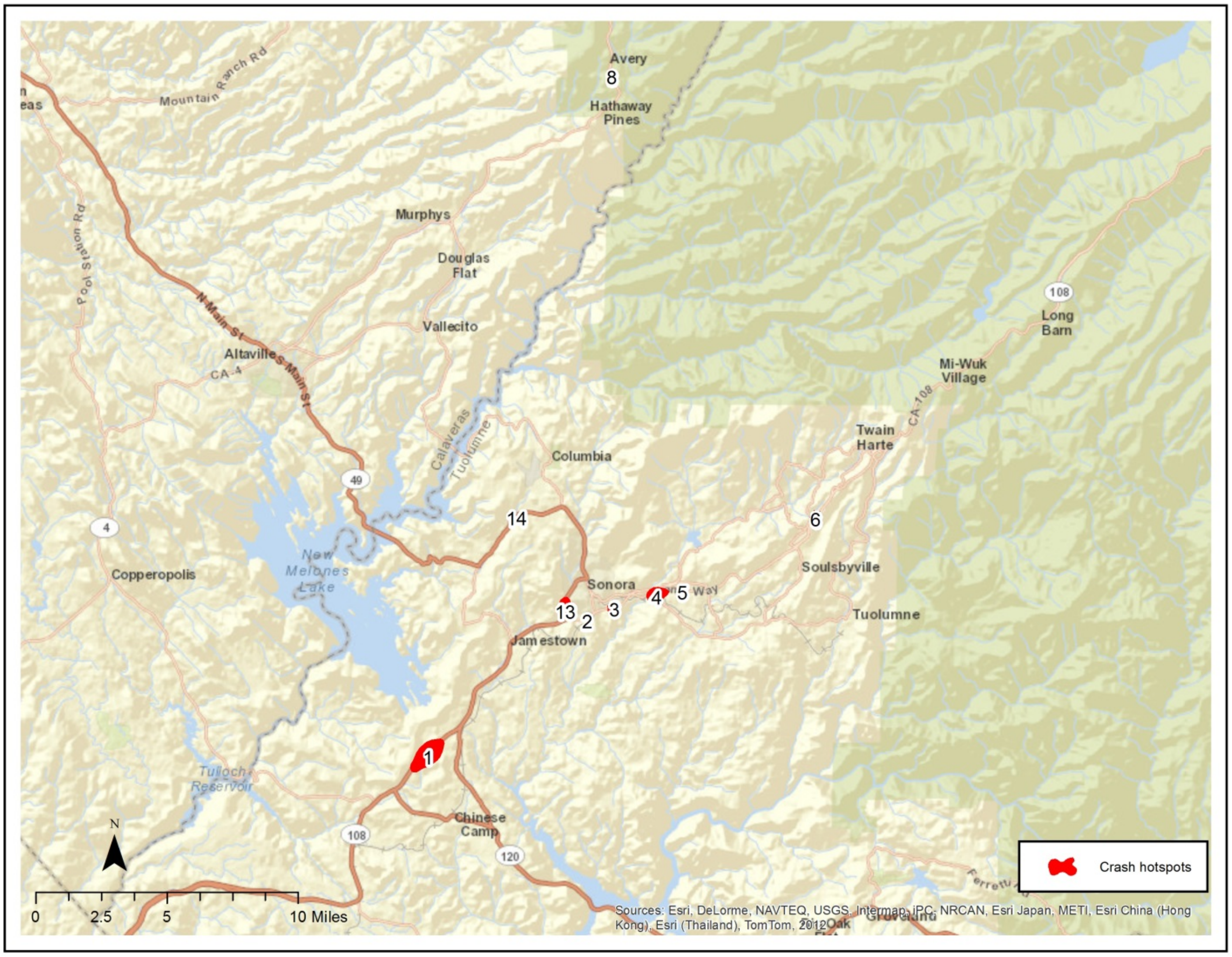

Figure 12: Overview map of the locations of the crash hotspots, northern portion of Caltrans District 10.

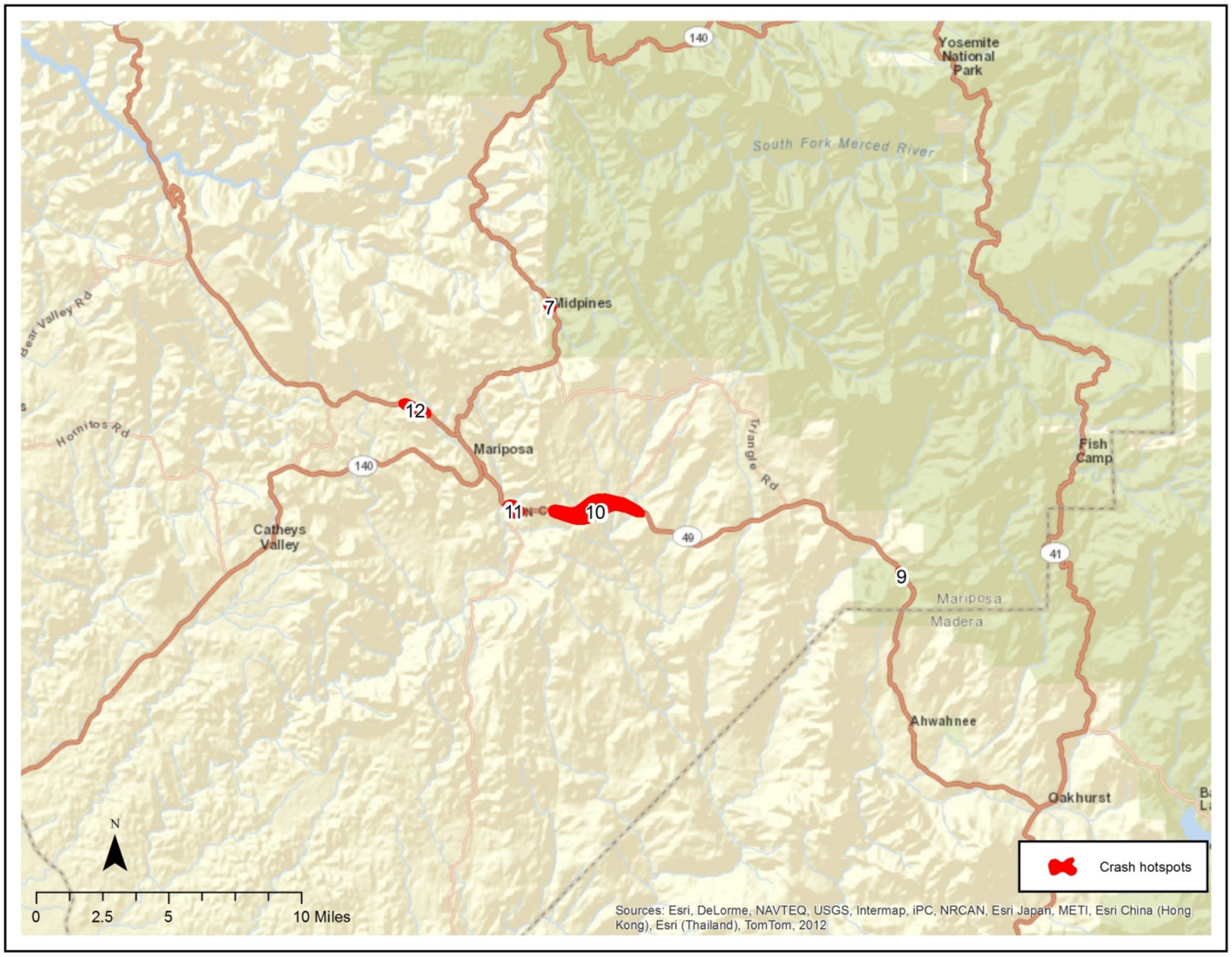

Figure 13: Overview map of the locations of the crash hotspots, southern portion of Caltrans District 10.

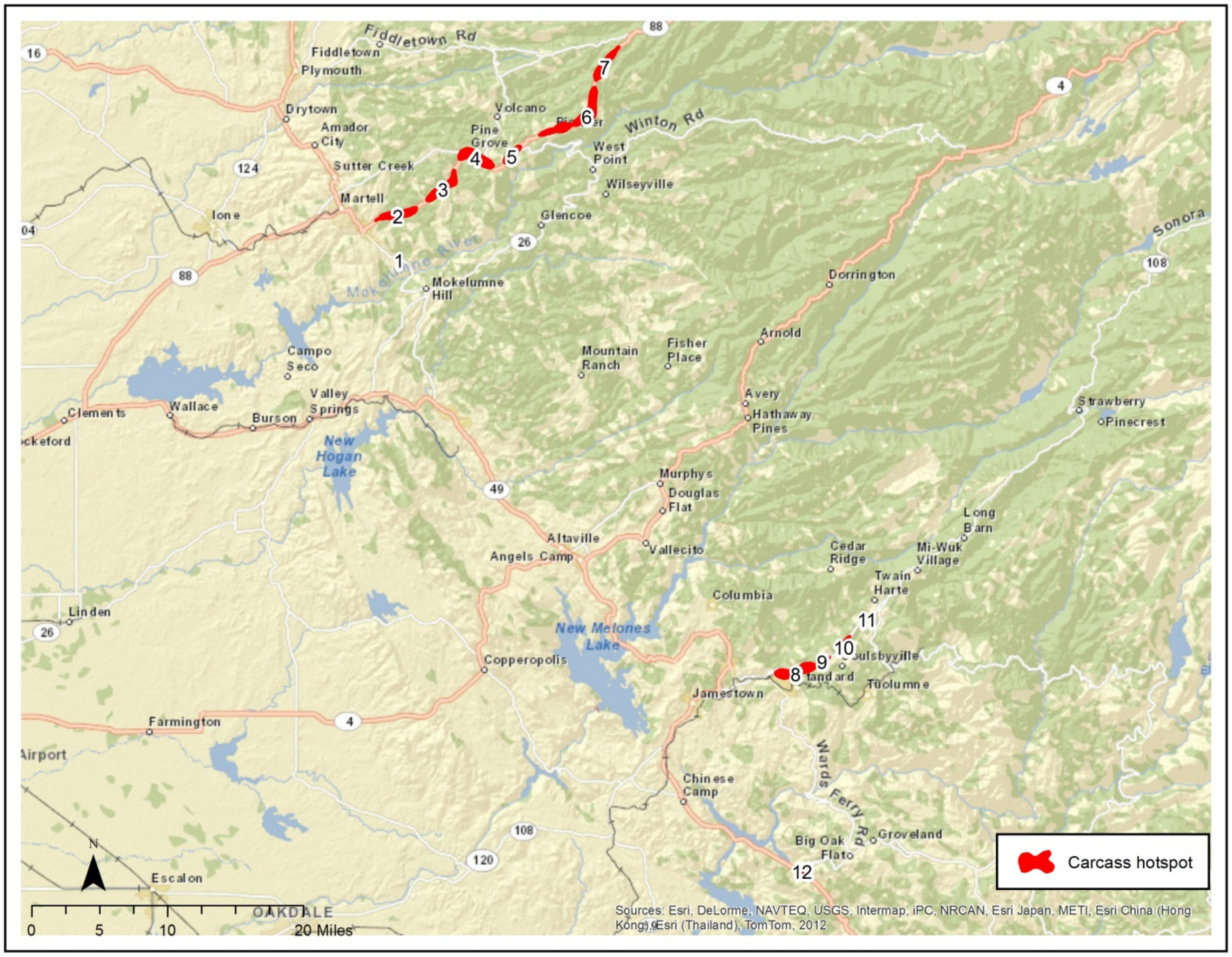

Figure 14: Overview map of the locations of the carcass hotspots in Caltrans District 10.

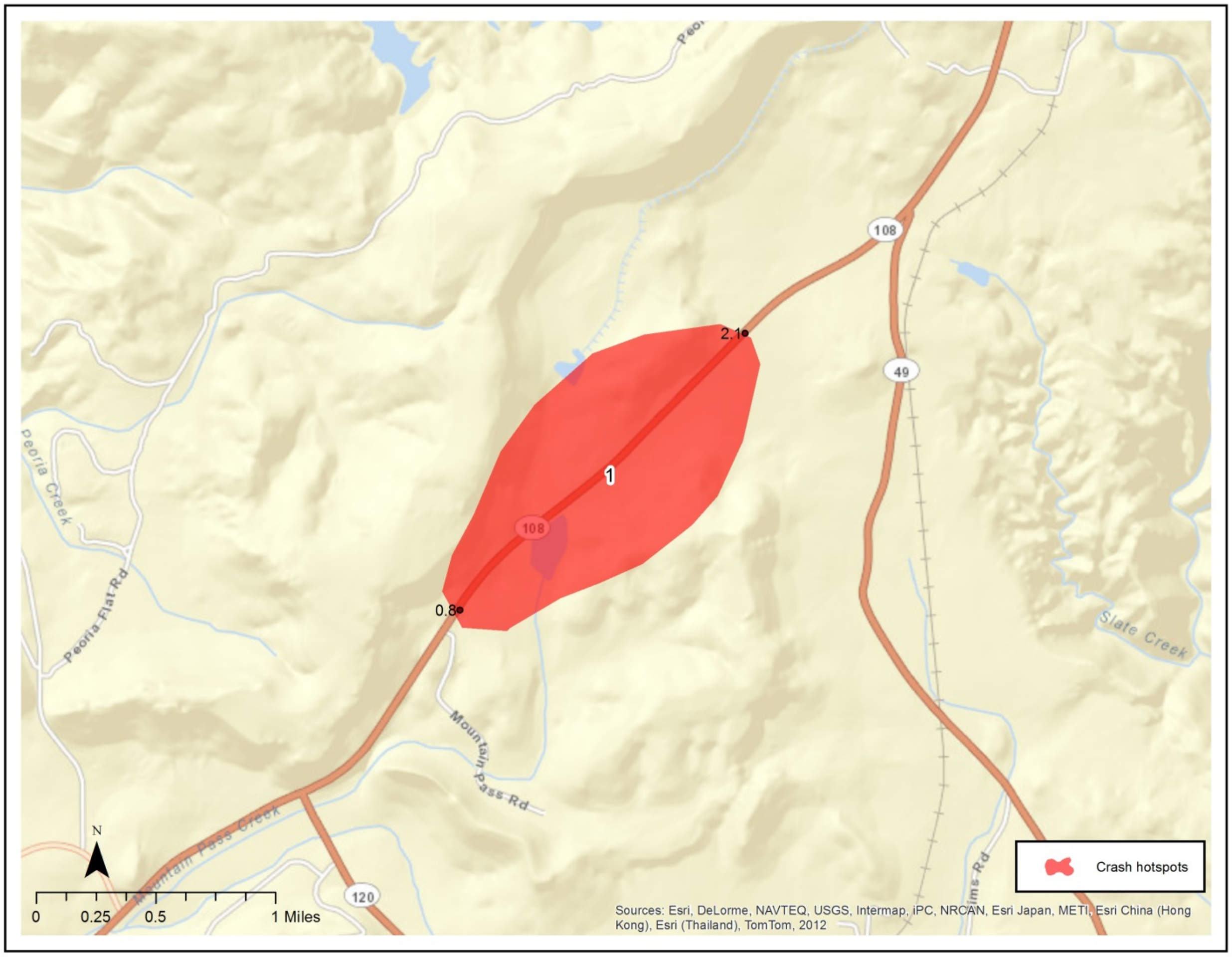

Figure 15: Detailed map of the crash 1 hotspot.

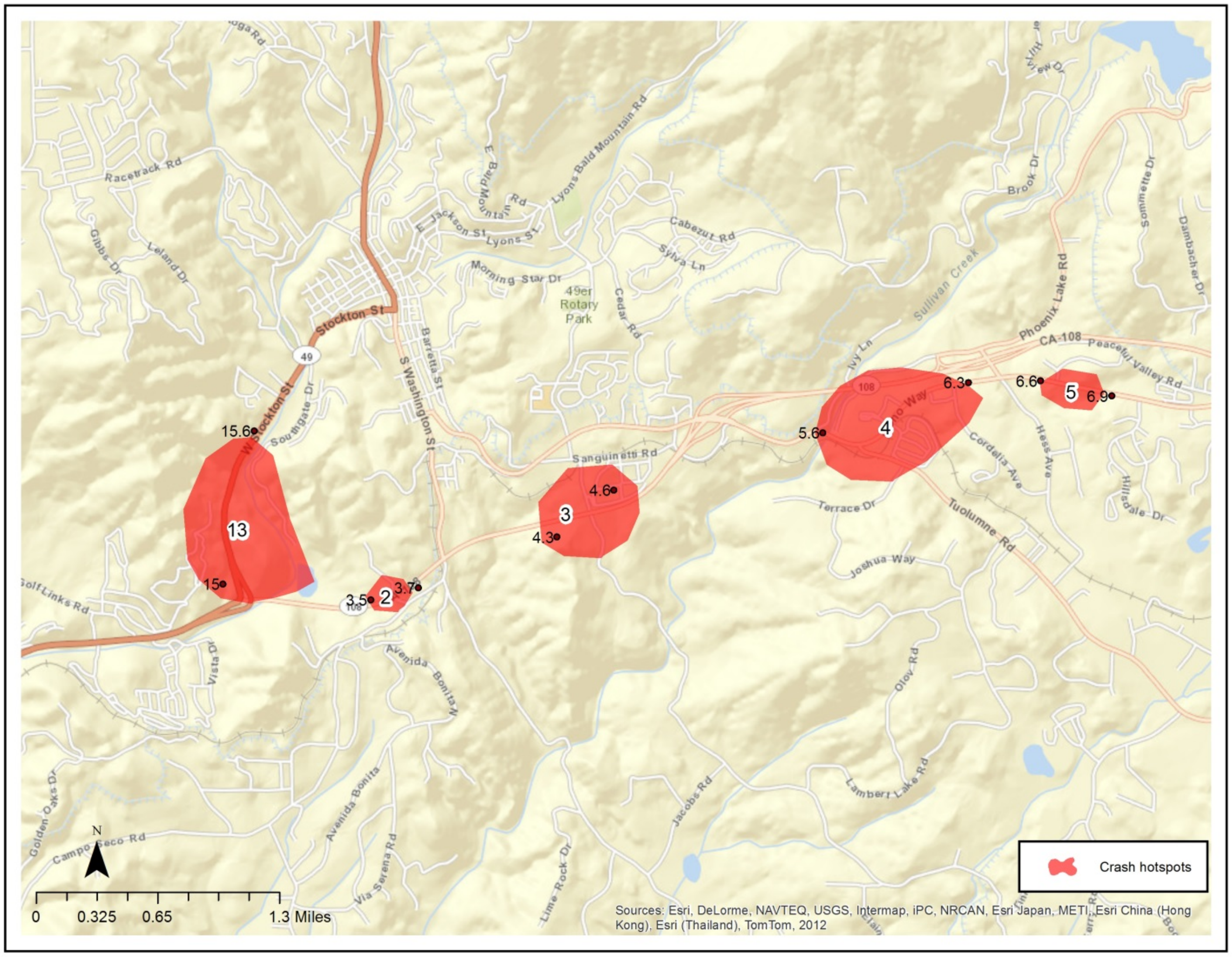

Figure 16: Detailed map of the crash 2 through 5 and 13 hotspots.

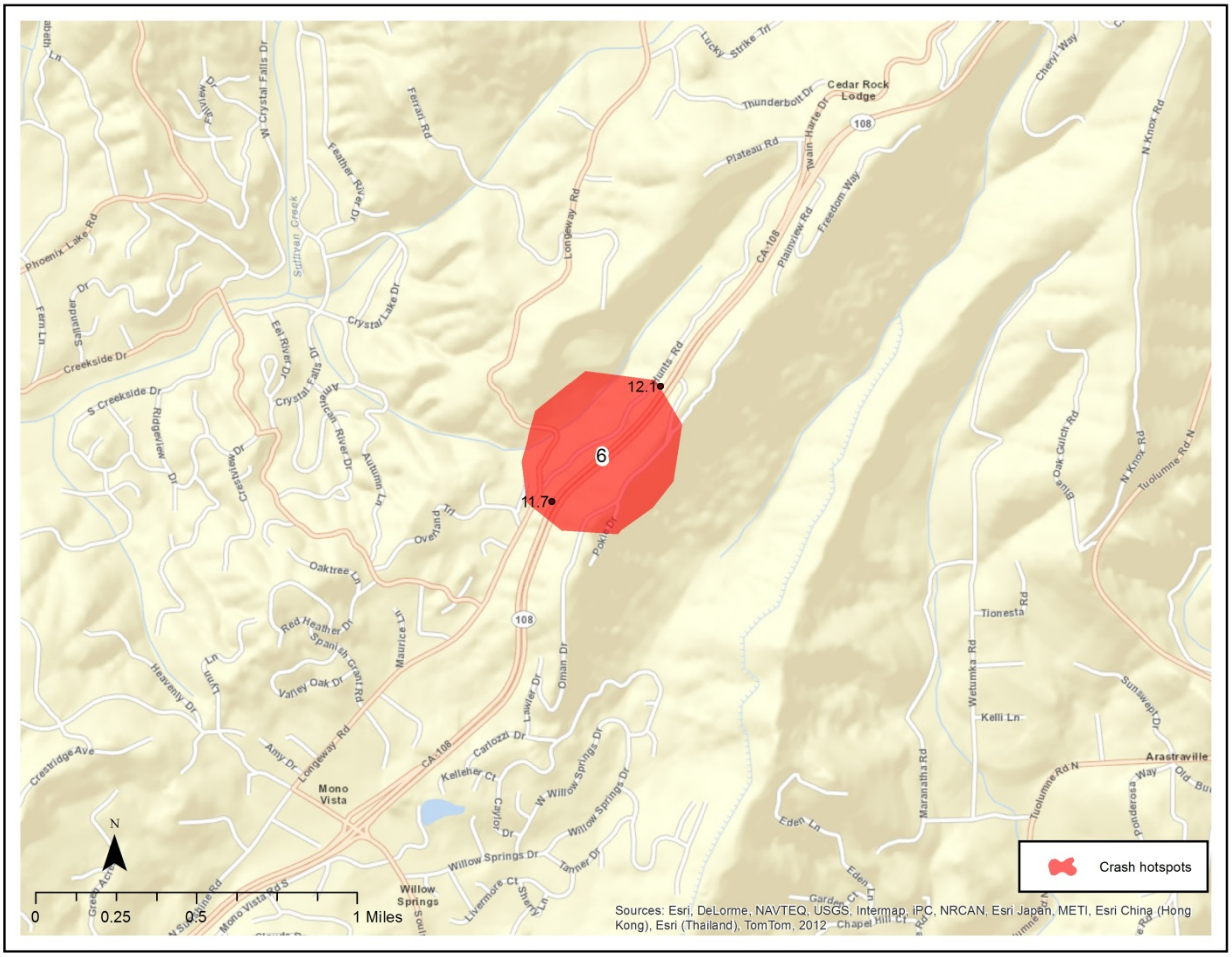

Figure 17: Detailed map of the crash 6 hotspot.

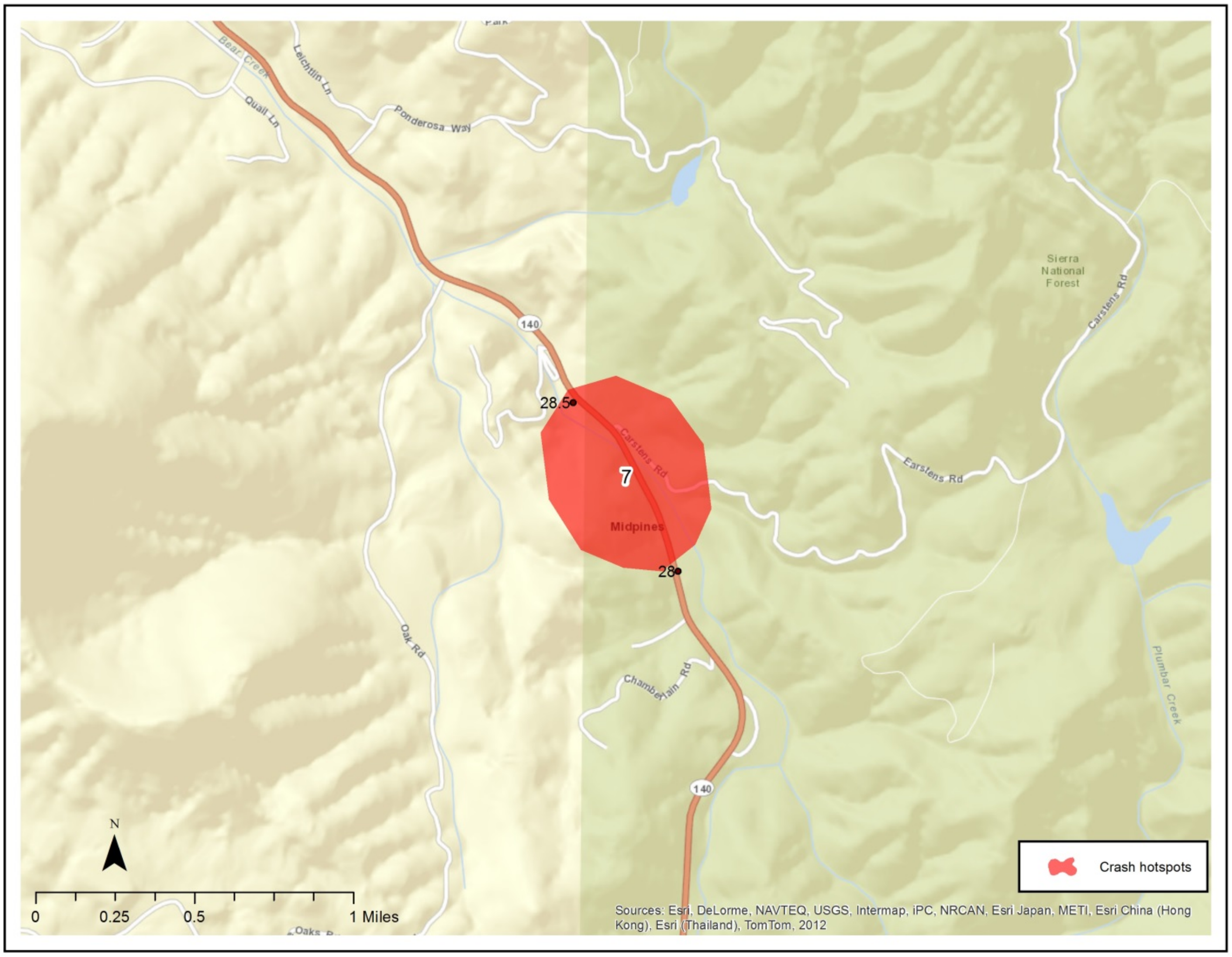

Figure 18: Detailed map of the crash 7 hotspot.

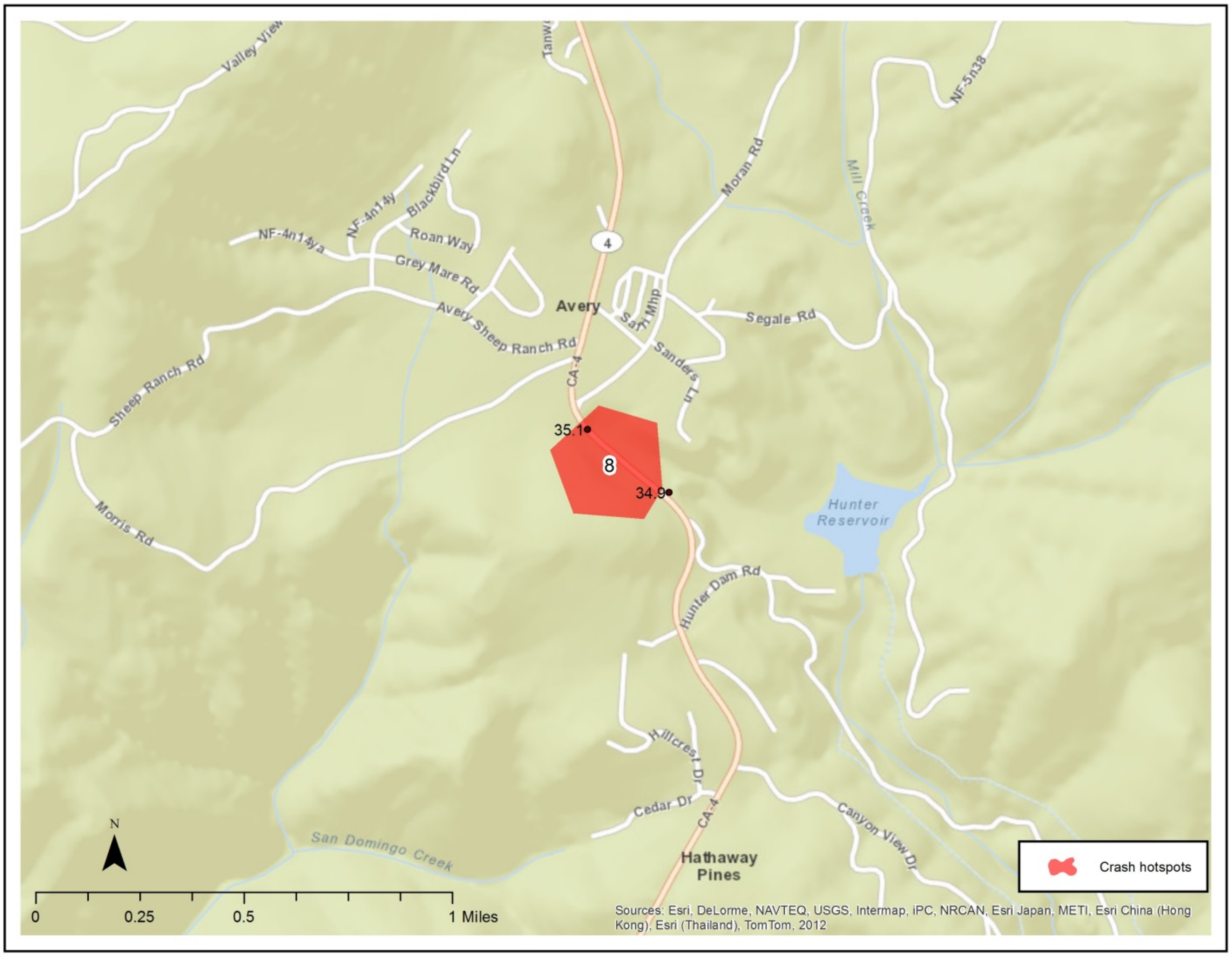

Figure 19: Detailed map of the crash 8 hotspot.

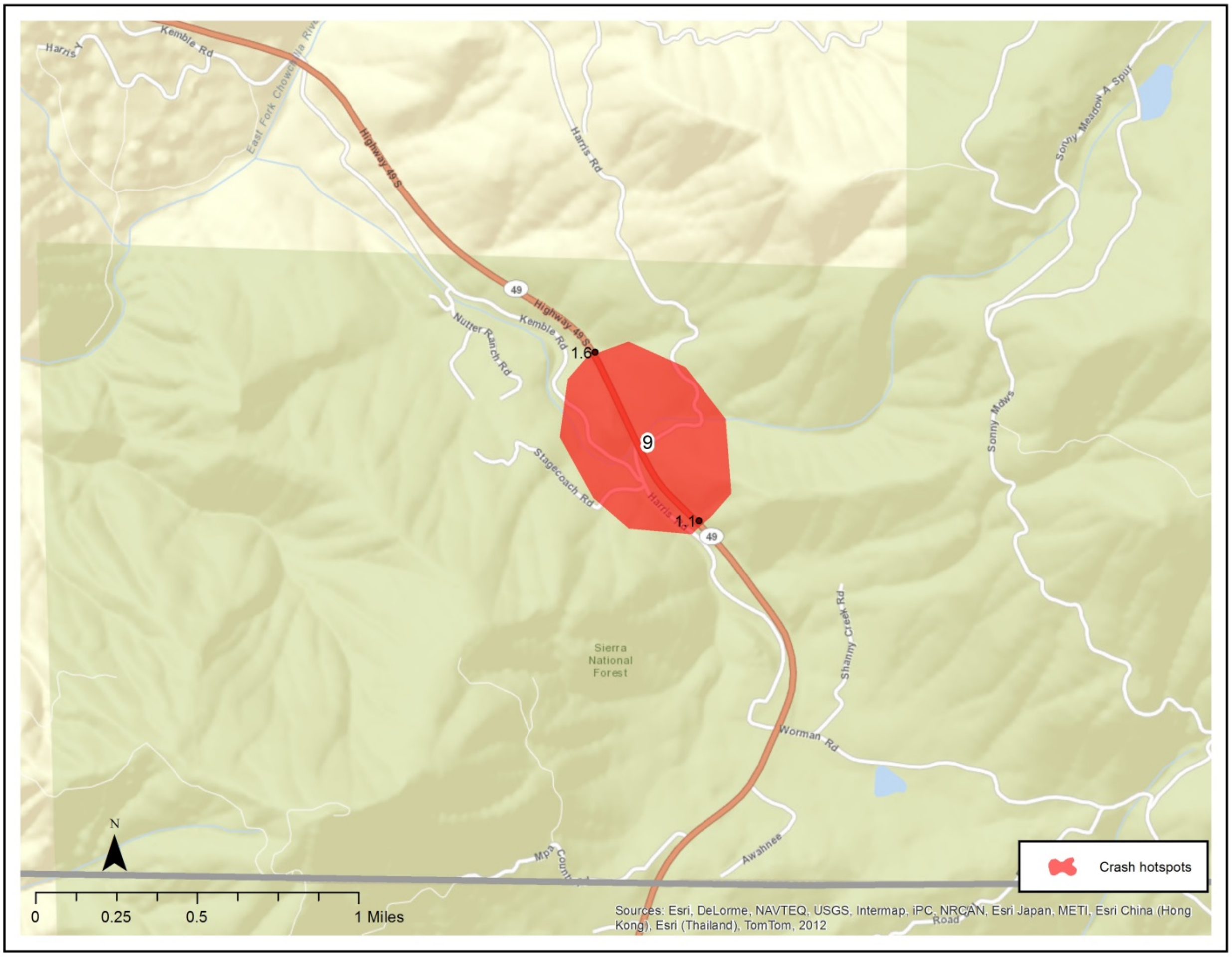

Figure 20: Detailed map of the crash 9 hotspot.

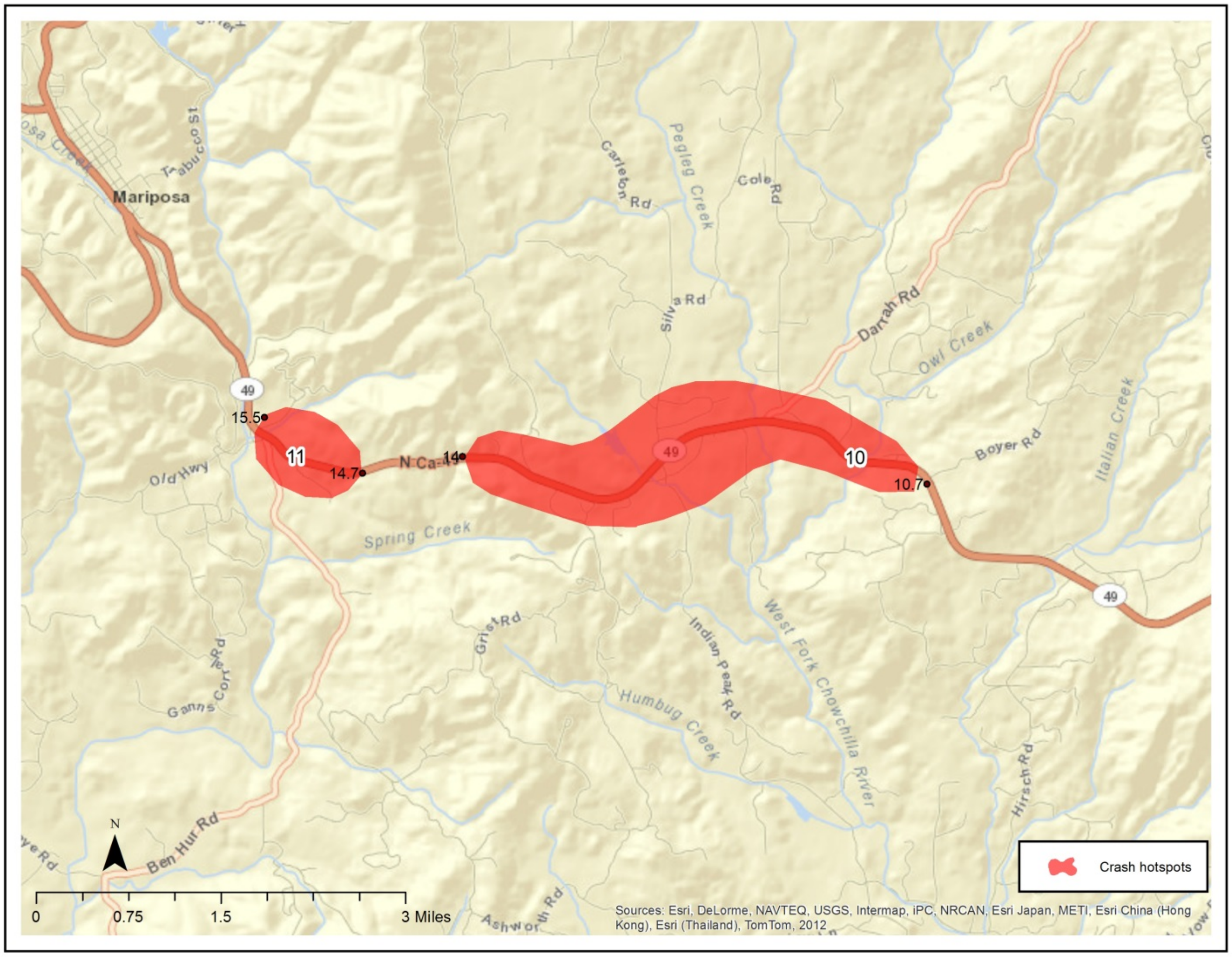

Figure 21: Detailed map of the crash 10 and 11 hotspot.

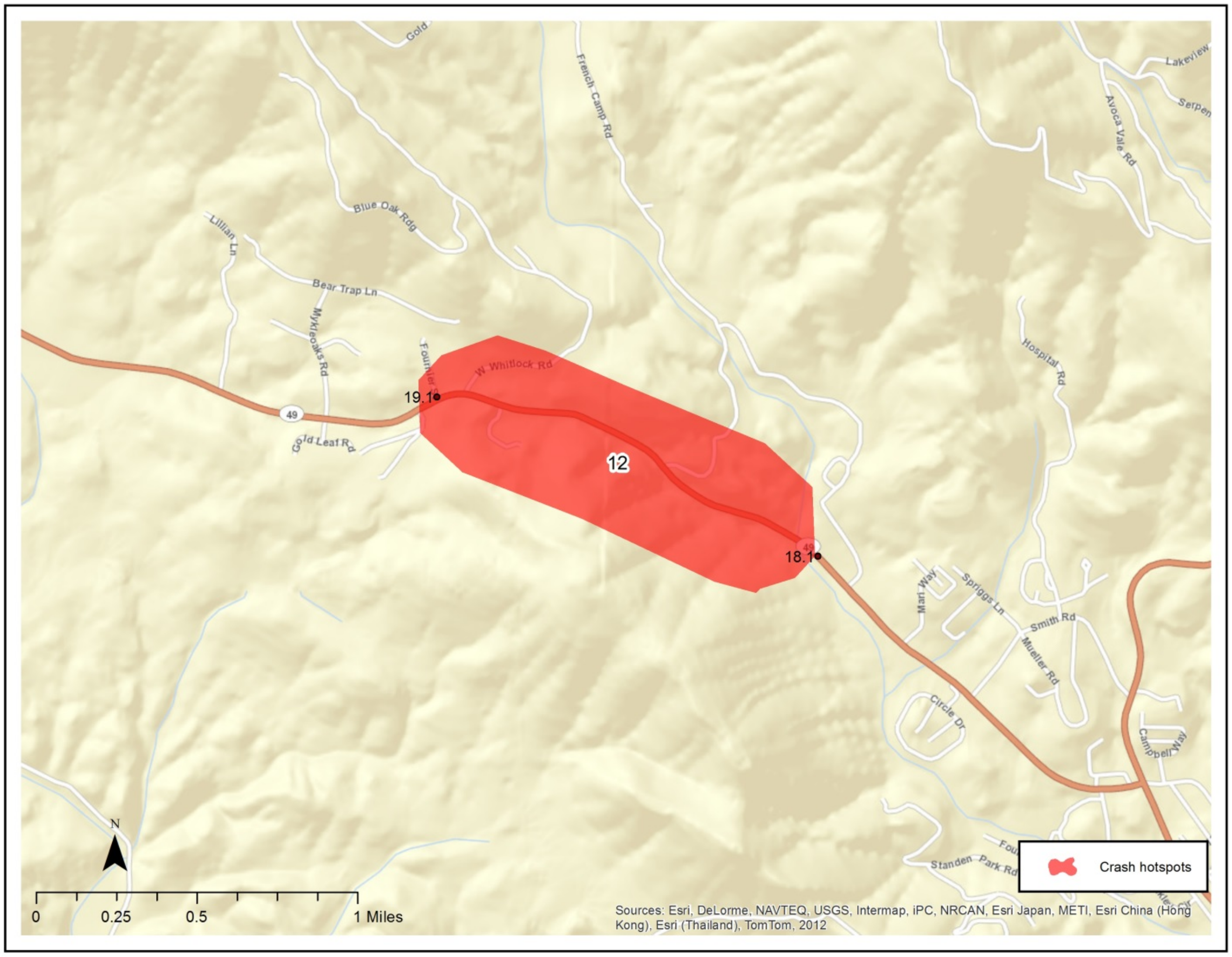

Figure 22: Detailed map of the crash 12 hotspot.

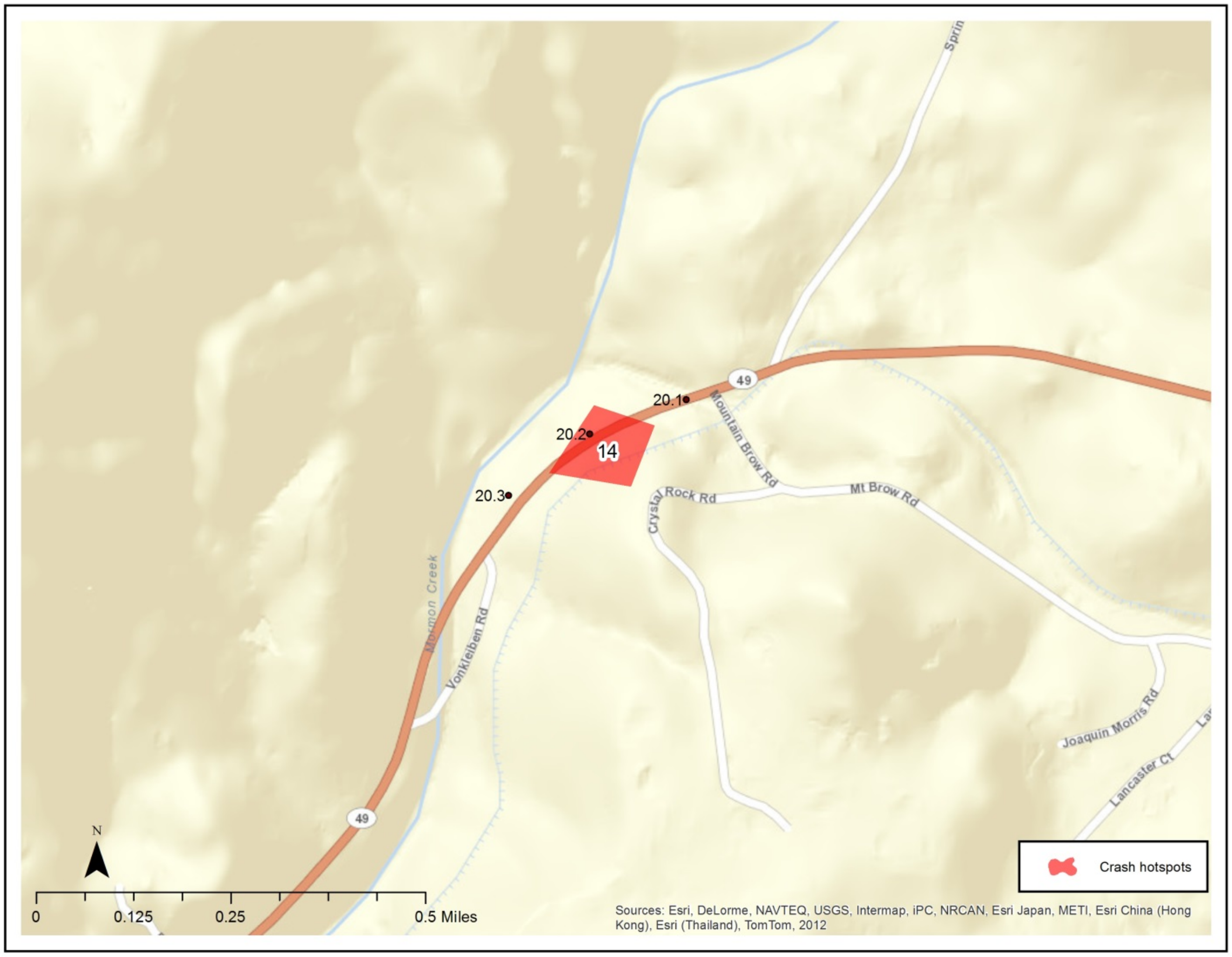

Figure 23: Detailed map of the crash 14 hotspot.

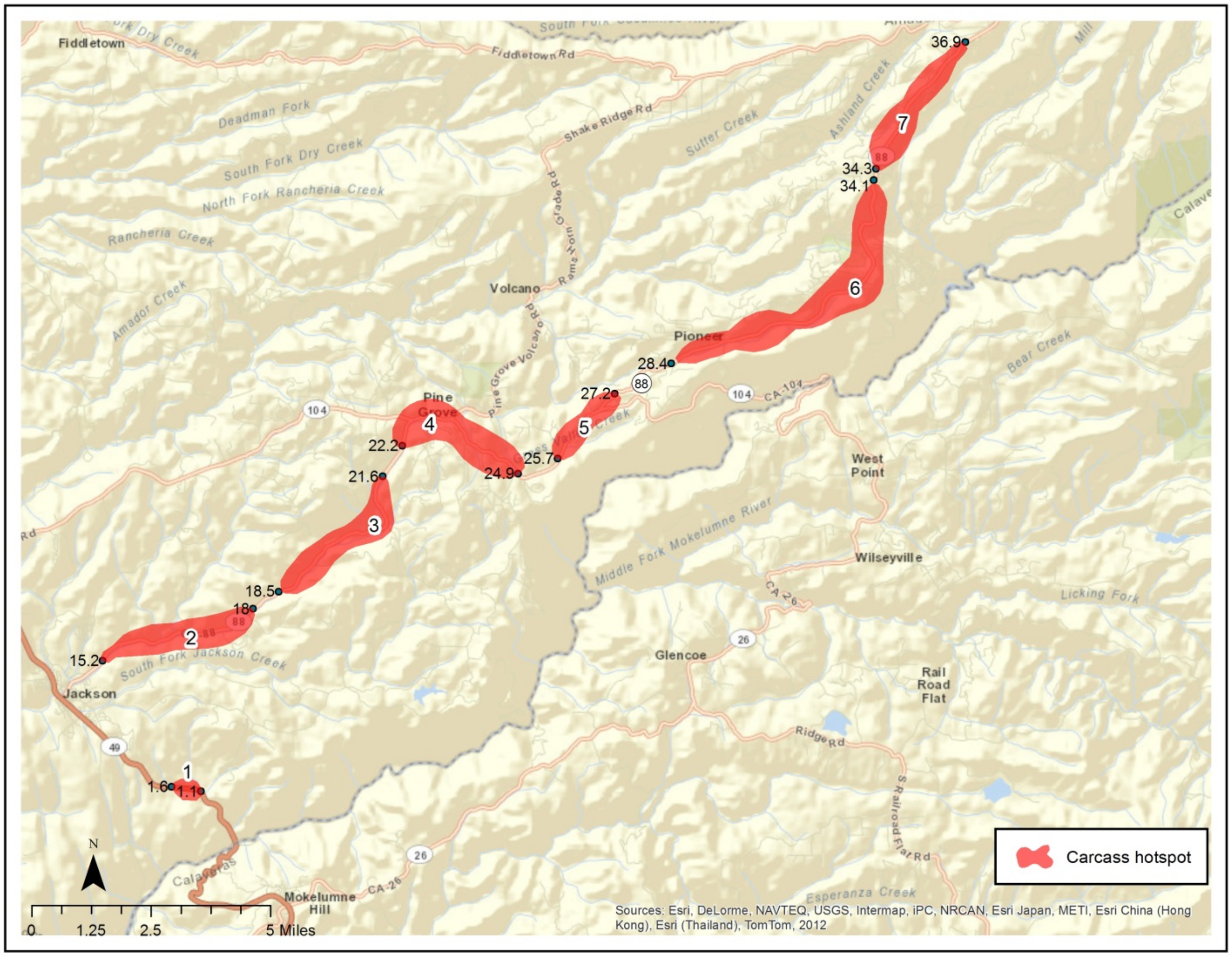

Figure 24: Detailed map of the carcass 1 through 7 hotspots.

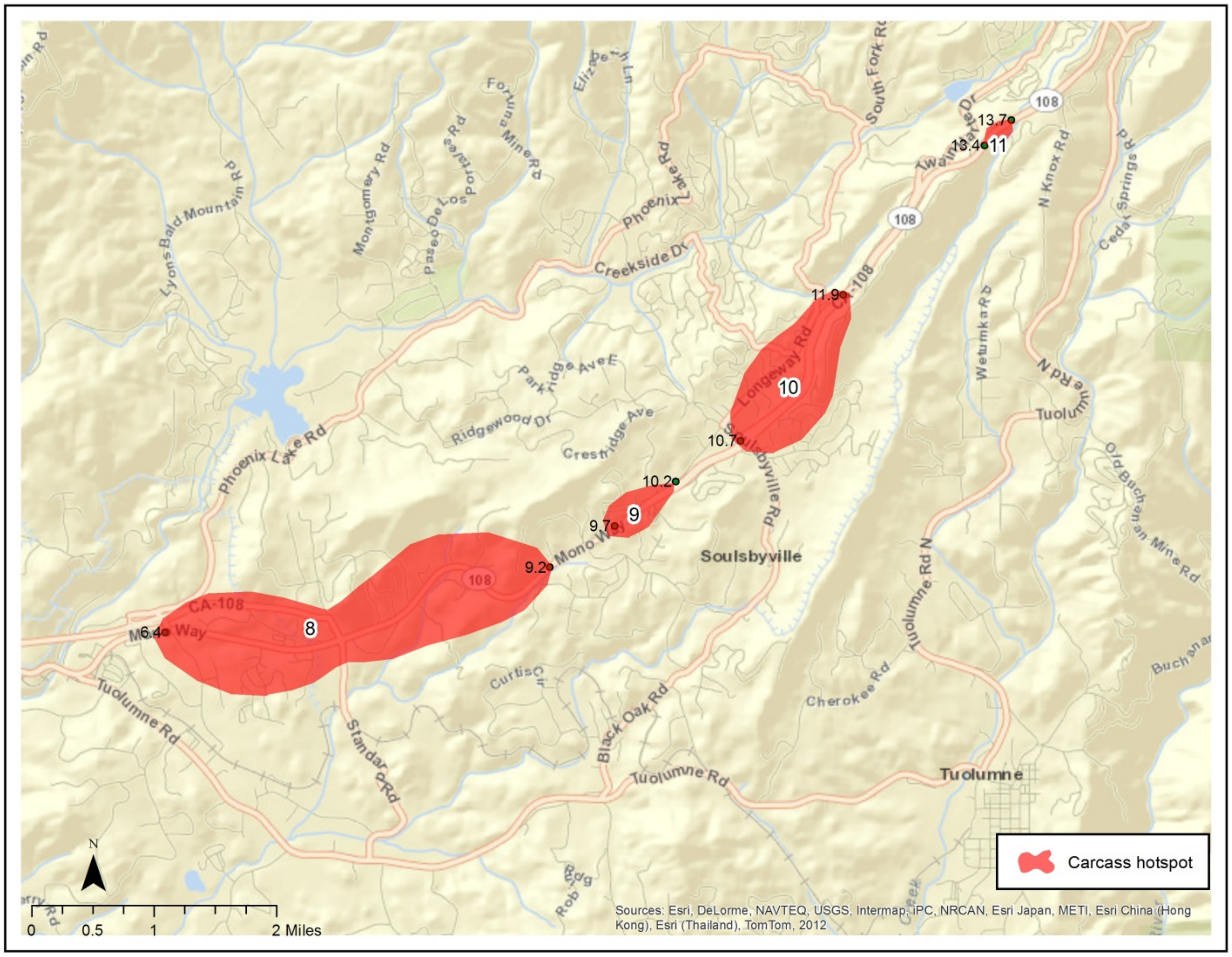

Figure 25: Detailed map of the carcass 8 through 11 hotspots.

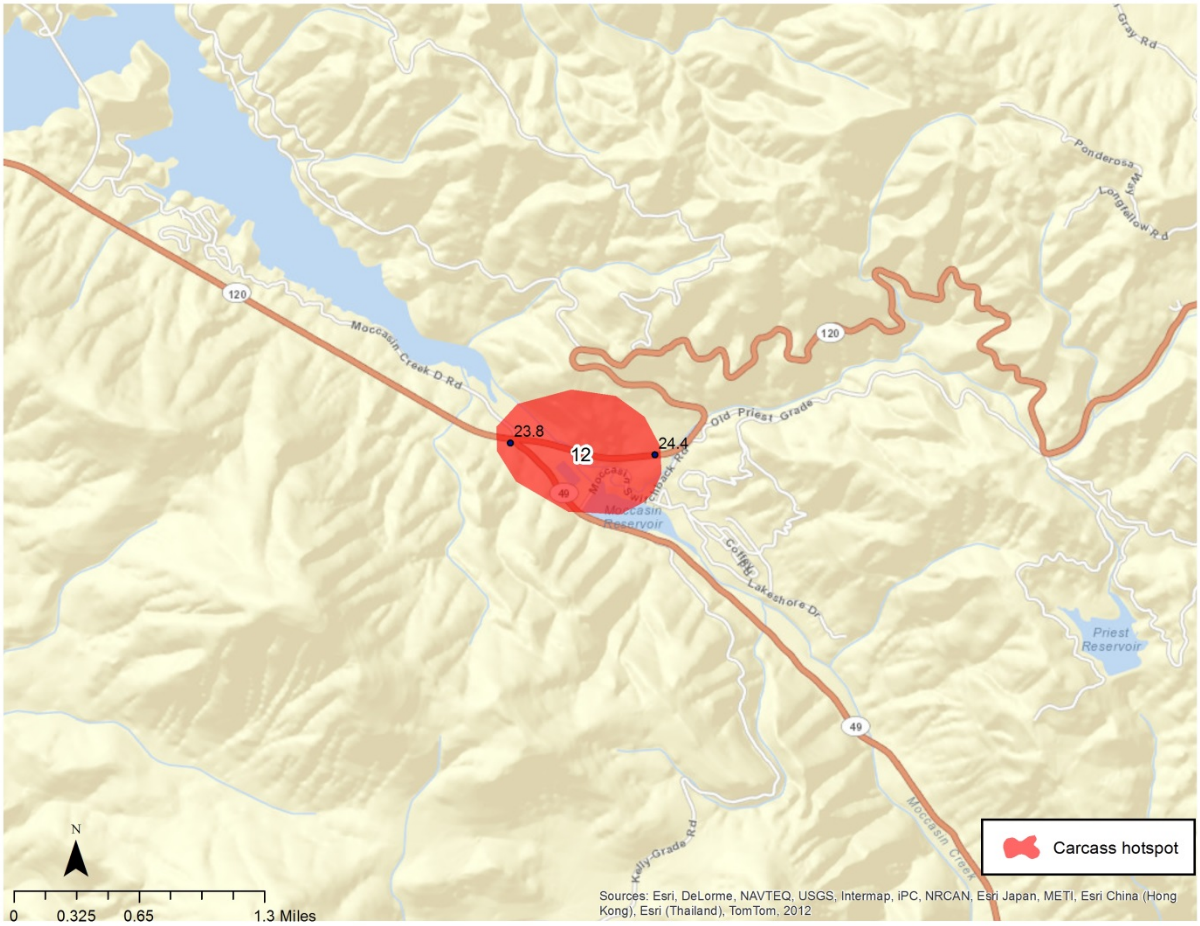

Figure 26: Detailed map of the carcass 12 hotspot.

3.8. Comparison Crash and Carcass Hotspots

While there is some overlap between the crash and carcass hotspots, there are also differences. In general both the crash and carcass hotspots appear concentrated in the western foothills of the (about 396-1463 m (1300-4800 ft) elevation) Sierra Nevada (Figure 10 and 11). Crash hotspots occur mostly in the southern portion of Caltrans District 10 around Mariposa and also in the center around Jamestown whereas carcass hotspots occur mostly in the north around Jackson and also in the center around Jamestown.

The differences in locations for the crash and carcass hotspots (mostly the crashes around Mariposa versus the carcasses around Jackson) are likely related to geographical differences in search and reporting effort for the crash data, the carcass data or both. While it seems likely that the search and reporting effort for carcass data is less consistent in time than the search and reporting effort for crash data (Figure 4 and 5), this does not necessarily mean that the search and reporting effort for carcass data is also less consistent spatially. Therefore the researcher recommend using both crash and carcass data when deciding if and where to implement mitigation measures aimed at reducing collisions with deer.

4. STEPWISE APPROACH: IDENTIFY CRASH AND CARCASS HOTSPOTS THAT ARE MOST IMPORTANT TO NATURE CONSERVATION

4.1. Nature Conservation Parameters

The researchers used existing maps generated through the California Essential Habitat Connectivity Project (Spencer et al., 2010) to identify areas that are considered most important to nature conservation. The maps distinguish between “Natural Landscape Blocks” and “Essential Connectivity Areas”. Natural Landscape Blocks are relatively large areas (blocks ≥10,000 acres (≥4,047 ha)) with relatively high nature conservation values and Essential Connectivity Areas are paths of least resistance between these Natural Landscape Blocks (Spencer et al., 2010).

The researchers also enquired with Caltrans maintenance personnel, and an employee of the Forest Service about potential species of concern (i.e. species that may be threatened or endangered on a federal or state level) or ecological processes (e.g. deer migration) that may be present in or near the crash or carcass hotspots. This is important as the potential implementation of mitigation measures aimed at reducing deer-vehicle collisions should not increase the barrier effect of roads and traffic on other species, particularly not for species which may already be threatened or endangered.

4.2. California Essential Habitat Connectivity Maps

The Natural Landscape Blocks and the Essential Connectivity Areas in Caltrans District 10 are shown in Figure 27. Figure 28 and 29 show the crash and carcass data with the Natural Landscape Blocks and the Essential Connectivity Areas in the background.

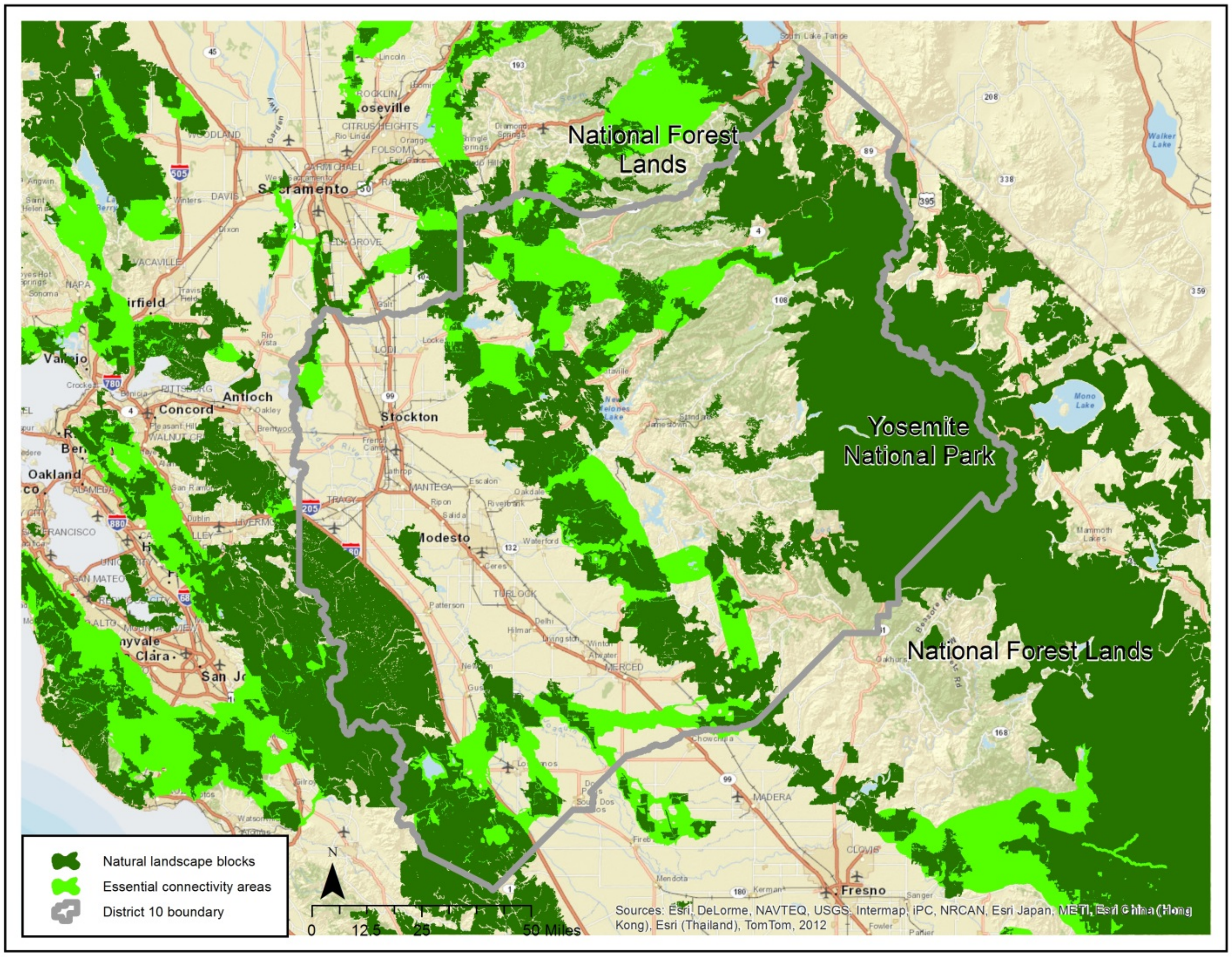

Figure 27: The Natural Landscape Blocks and Essential Connectivity Areas in Caltrans District 10 (Spencer et al., 2010).

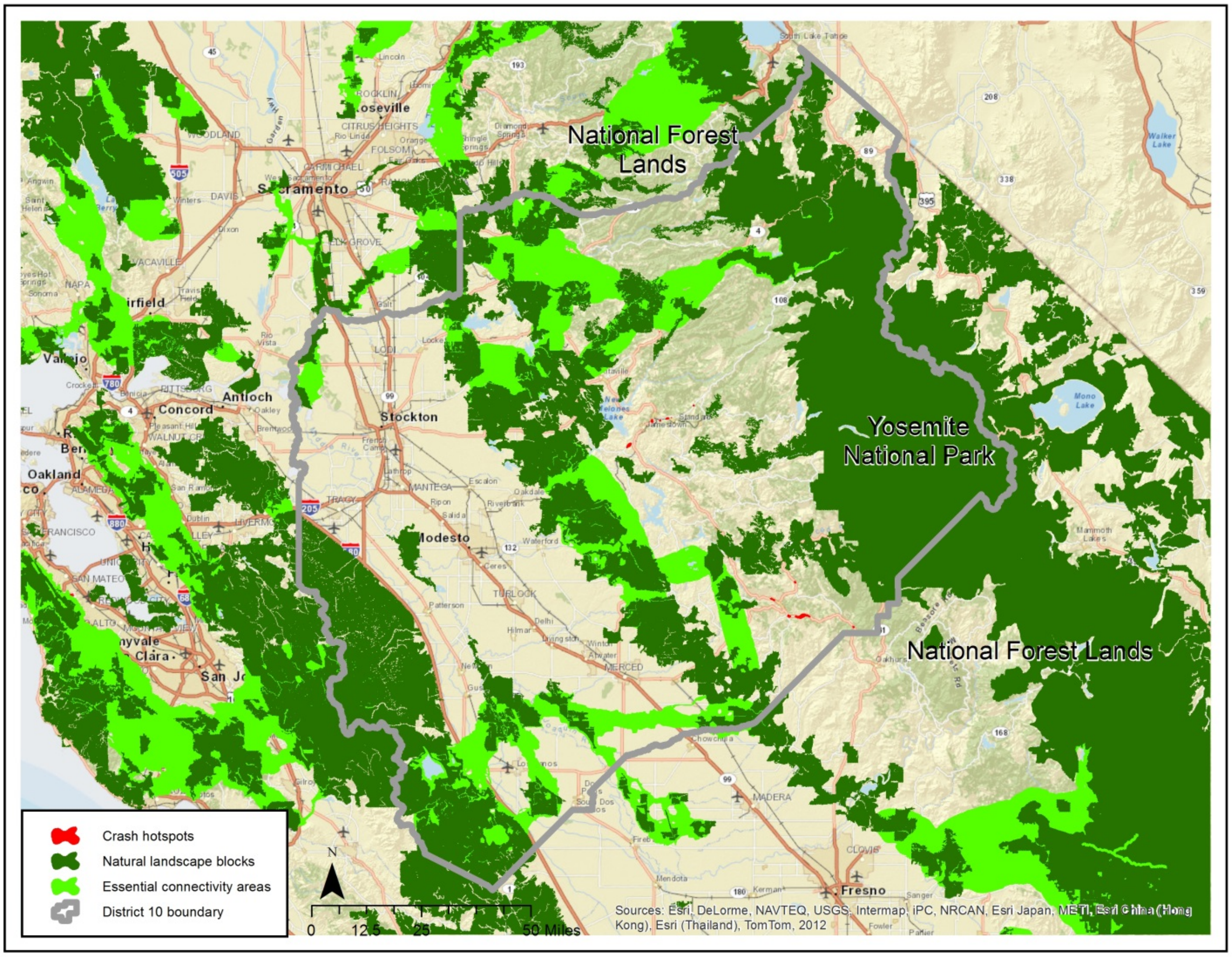

Figure 28: The crash hotspots and the Natural Landscape Blocks and Essential Connectivity Areas in Caltrans District 10.

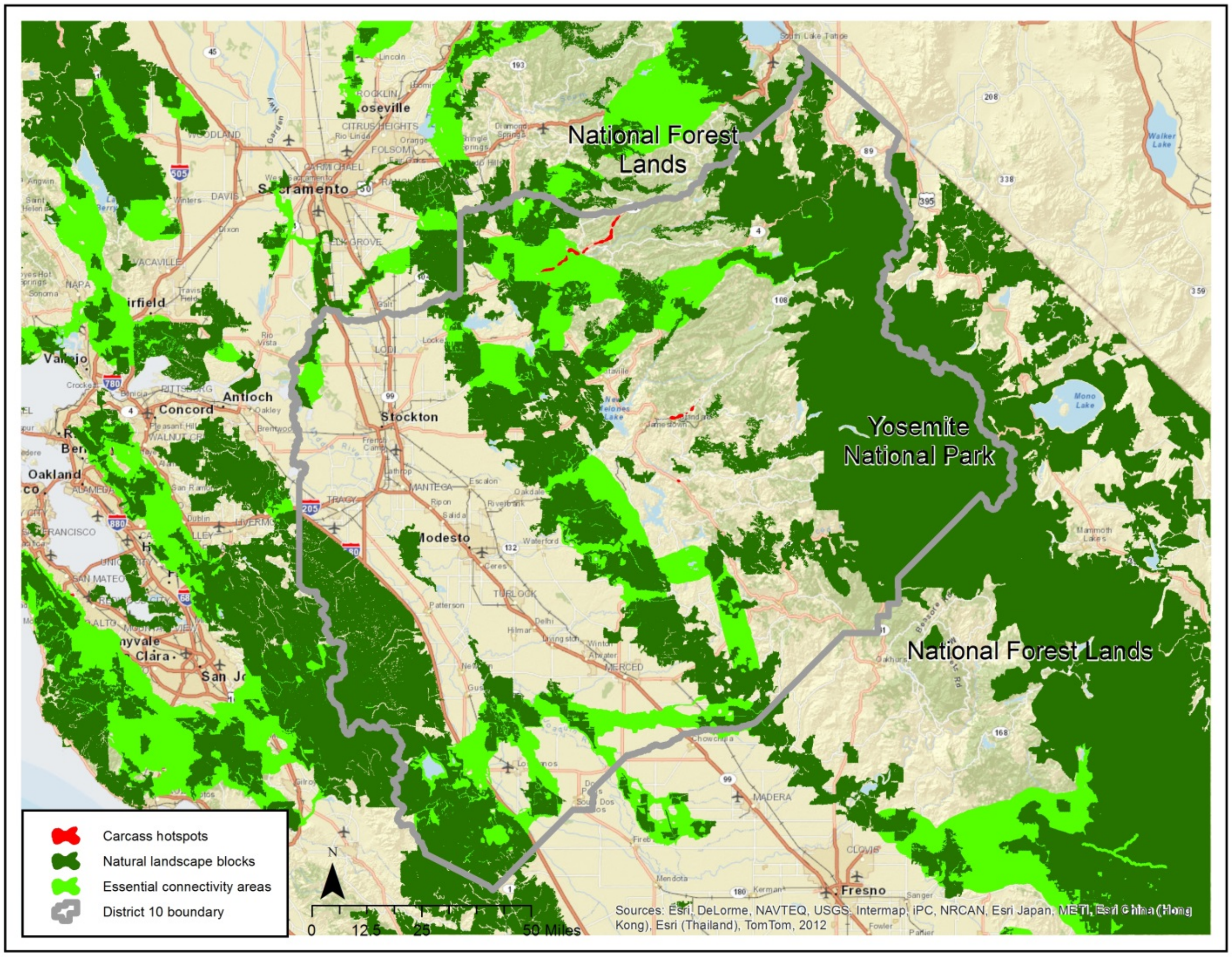

Figure 29: The carcass hotspots and the Natural Landscape Blocks and Essential Connectivity Areas in Caltrans District 10.

4.3. Species of Concern and Ecological Processes

The researchers enquired about potential species of concern or important ecological processes with the following sources:

- Critical habitat for threatened and endangered species (U.S. Fish and Wildlife Service, 2013a). The researchers compared the location of the crash and carcass hotspot to the critical habitat for threatened and endangered species. None of the hotspots were in or adjacent to critical habitat.
- Federally endangered and threatened species present in the counties with crash or carcass hotspots (U.S. Fish & Wildlife Service, 2013b). The researchers listed all amphibian, reptile and mammal species that may be present in the counties that have crash or carcass hotspots (Table 8).

Table 8: The federally endangered and threatened species (amphibians, reptiles and mammals only) present in the counties with crash or carcass hotspots (U.S. Fish & Wildlife Service, 2013b).

		County			
Species name	Scientific species name	Amador	Calaveras	Tuolumne	Mariposa
Amphibians					
California tiger salamander, centr. pop.(T)	*Ambystoma californiense*	x	x	x	x
California red-legged frog (T)	*Rana draytonii*	x	x	x	x
Mountain yellow legged frog (PX)	*Rana sierrae*	x	x	x	x
Mountain yellow-legged frog (C)	*Rana muscosa*	x	x	x	x
Yosemite toad (PX)	*Anaxyrus canorus*	x	x	x	x
Yosemite toad (C)	*Bufo canorus*	x	x	x	x
Reptiles					
Giant garter snake (T)	*Thamnophis gigas*	x	x	x	x
Blunt-nosed leopard lizard (E)	*Gambelia (=Crotaphytus) sila*				x
Mammals					
Fisher (C)	*Martes pennanti*	x	x	x	x
San Joaquin kit fox (E)	*Vulpes macrotis mutica*		x	x	x
Sierra Nevada (=California) bighorn sheep (E)	*Ovis canadensis californiana*			x	
Fresno kangaroo rat (E)	*Dipodomys nitratoides exilis*				x
(T) Threatened - Listed as likely to become endangered within the foreseeable future.					
(PX) Proposed Critical Habitat - The species is already listed. Critical habitat is being proposed for it.					
(P) Proposed - Officially proposed in the Federal Register for listing as endangered or threatened.					
(C) Candidate - Candidate to become a proposed species.					

While these species are on the list for the respective counties, they may not actually occur near the crash and carcass hotspots. Detailed distribution maps (e.g. Nature Mapping Foundation, 2013; California Herps, 2013) may be consulted to verify if certain species are indeed known to occur at or near specific sites. Species for which mitigation measures at selected hotspots could perhaps be beneficial, now or in the future, are California red legged frog, mountain yellow legged frog (or Sierra Nevada yellow-legged frog (*Rana sierrae*)), Yosemite toad, fisher, at all crash and carcass hotspots (except perhaps crash hotspot 1).

Note that the crash and carcass hotspots are unlikely to overlap with the current range of the giant garter snake, blunt-nosed leopard lizard, San Joaquin kit fox, Sierra Nevada bighorn sheep, or Fresno kangaroo rat.

- Caltrans maintenance crews (Pinegrove area and Jamestown area) and Forest Service personnel (Pine grove area). Wildlife fencing aimed at mule deer can be expected to also be a barrier to other medium and large mammal species. Therefore the researchers interviewed Caltrans maintenance personnel and Forest Service personnel in the Pinegrove and Jamestown area with regard to the occurrence of medium and large mammals in the area, independent of their conservation status (Table 9). In addition the researchers enquired about important ecological processes such as seasonal migration.

Table 9: The medium and large mammals believed to be present at or near the crash or carcass hotspots (U.S. Fish & Wildlife Service, 2013b).

Species name	Scientific species name	(Caltrans) Pinegrove area	Chuck Loffland (Forest Service), Pinegrove area	Tony Lertora (Caltrans), Jamestown area
Squirrels	Sciuridae	x		
North American porcupine	*Erethizon dorsatum*	x	x	
Beaver	*Castor canadensis*			x
Virginia opossum	*Didelphis virginiana*		x	x
Northern raccoon	*Procyon lotor*	x		x
Ringtail	*Bassariscus astutus*	x	x	
Striped skunk	*Mephitis mephitis*		x	
Western spotted skunk	*Spilogale gracilis*		x	
Skunks	Mephitidae	x		
Fisher	*Martes pennanti*	x	x	
Badger	*Taxidea taxus*	x		
Wolverine	*Gulo gulo*		x	
Bobcat	*Lynx rufus*	x	x	
Mountain lion	*Puma concolor*	x	x	
Grey fox	*Urocyon cinereoargenteu*		x	
Sierra Nevada red fox	*Vulpes vulpes necator*		x	
Coyotes	*Canis latrans*	x		
Mule deer	*Odocoileus hemionus*		x	x
Black bear	*Ursus americanus*	x	x	x

Note:

- North American porcupine, beaver (particularly at stream crossings or near water) Porcupine, fisher, wolverine, at all crash and carcass hotspots (except perhaps crash hotspot 1).

- Squirrels, Virginia opossum, northern raccoon, ringtail, striped skunk, western spotted skunk, badger, bobcat, mountain lion, grey fox, coyotes, mule deer, and black bear at all crash and carcass hotspots. There is a distinct seasonal migration of mule deer up and down the slopes on the western Sierra Nevada, including where many of the carcass hotspots are located. However, some deer are now believed to stay year round at lower elevation, partially because some people feed the deer.

- Note that the crash and carcass hotspots are unlikely to overlap with the current range of the Sierra Nevada red fox (only known around Sonora pass at high elevation) and wolverine (high elevation only).

4.4. Ranking Hotspots Based on Value to Nature Conservation

Tables 10 and 11 list the length of the crash and carcass hotspots and whether the hotspots are located in a Natural Landscape Block or Essential Connectivity Area. These parameters were used to rank the hotspots for nature conservation. These rankings also also used later (Chapter 6) to finalize the prioritization of the hotspots. Note that There was relatively little distinction between the hotspots with regard to the potential presence of threatened and endangered species.

Table 10: The length of the road segments with the crash hotspots, whether the individual hotspots are located in a Natural Landscape Block or Essential Connectivity Area, and the ranking for Nature Conservation. The ranking was based first on the potential location in a Natural Landscape Block, and, in case of a tie, also on the potential location in an essential connectivity area.

Hotspot ID	Length (mi)	Hotspot in Natural Landscape Block?	Hotspot in Essential Connectivity Area?	Ranking nature conservation
Crash 1	1.4	No	No	n/a
Crash 2	0.2	No	No	n/a
Crash 3	0.4	No	No	n/a
Crash 4	0.8	No	No	n/a
Crash 5	0.3	No	No	n/a
Crash 6	0.5	No	No	n/a
Crash 7	0.6	No	No	n/a
Crash 8	0.3	No	No	n/a
Crash 9	0.6	No	No	n/a
Crash 10	3.3	No	No	n/a
Crash 11	0.8	No	No	n/a
Crash 12	1.1	No	No	n/a
Crash 13	0.6	No	No	n/a
Crash 14	0.1	No	No	n/a

Table 11: The length of the road segments with the carcass hotspots, whether the individual hotspots are located in a Natural Landscape Block or Essential Connectivity Area, and the ranking for Nature Conservation. The ranking was based first on the potential location in a Natural Landscape Block, and, in case of a tie, also on the potential location in an essential connectivity area.

Hotspot ID	Length (mi)	Hotspot in Natural Landscape Block?	Hotspot in Essential Connectivity Area?	Ranking nature conservation
Carcass 1	0.5	No	Yes	1*
Carcass 2	2.9	No	Yes	1*
Carcass 3	3.1	No	Yes	1*
Carcass 4	2.7	No	Yes	1*
Carcass 5	1.6	No	No	n/a
Carcass 6	5.6	No	No	n/a
Carcass 7	2.6	No	No	n/a
Carcass 8	2.9	No	No	n/a
Carcass 9	0.5	No	No	n/a
Carcass 10	1.4	No	No	n/a
Carcass 11	0.3	No	No	n/a
Carcass 12	0.7	No	No	n/a

***= tie**

5. STEPWISE APPROACH: IDENTIFY CRASH AND CARCASS HOTSPOTS WHERE ECONOMIC BENEFITS OF MITIGATION ARE GREATEST

5.1. Introduction

Over 40 types of mitigation measures aimed at reducing collisions with large ungulates have been described (see reviews in Hedlund et al. 2004, Knapp et al. 2004, Huijser et al. 2008). Examples include warning signs that alert drivers to potential animal crossings, wildlife warning reflectors or mirrors (e.g., Reeve and Anderson 1993, Ujvári et al. 1998), wildlife fences (Clevenger et al. 2001), and animal detection systems (Huijser et al. 2006). However, the effectiveness and costs of these mitigation measures vary greatly. When the effectiveness is evaluated in relation to the costs for the mitigation measure, important insight is obtained regarding which mitigation measures may be preferred, at least from a monetary perspective.

5.2. Methods

For the purpose of this report the researchers conducted cost-benefit analyses for four different types and combinations of mitigation measures for the highway segments with a crash or carcass hotspot in Caltrans District 10. The types and combinations of mitigation measures evaluated for this report included:

- Animal detection system
- Fence, gap (once every 2 km), animal detection system in gap, jump-outs
- Fence, under- and overpass (underpass once every 2 km, overpass once every 24 km), jump-outs
- Fence, under pass (once every 2 km), jump-outs

For details on the effectiveness and estimated costs of the mitigation measures per 0.62 mile (1 km) per year and other methodological aspects of the cost-benefit analyses see Huijser et al. (2009). This publication also provides a rationale for the estimated costs associated with each deer-vehicle collision ($6,617). While this value includes a line item for carcass removal ($50), the actual costs for carcass removal in Caltrans may be higher. It typically takes 2 people 1 hour to pick up and dispose of a deer carcass. The cost for large mammal-vehicle collisions is expressed in dollars per year per 0.62 mi (1 km). The cost estimates are based on a divided four lane highway (two lanes in each direction) as the mitigation measures are more likely to be implemented with an overall road reconstruction that involves a wider and higher capacity highway than the implementation of mitigation measures as a stand-alone project along a two lane road.

For the purpose of these cost-benefit analyses the researchers used both the crash and carcass data at each crash or carcass hotspot. The road sections for which the analyses were conducted started and ended 2 miles (2.22 km) before and after the actual crash or carcass hotspot, unless a junction with another highway was within two miles; then the junction was used as a start or end point for the cost-benefit analyses.

Note that the analyses are only based on crashes or carcasses. The analyses do not include other large mammal species such as black bear (*Ursus americanus*) that also occur within the district, though much less frequently than with deer. Since collisions with large mammals other than deer are likely only a very small proportion of the total number of collisions with large wild mammals the exclusion of large wild mammals other than deer is unlikely to influence the results very much. However, if passive use values would be included in the cost-benefit analyses, then species with a high conservation value could have a substantial influence on the outcome of the analyses.

5.3. Results

Figures 30-39 show for which road sections around the crash hotspots (1 through 14) the number of recorded deer crashes was high enough to meet or exceed thresholds for the implementation of four different types of mitigation measures. Figures 40-43 show for which road sections the number of recorded deer carcasses was high enough to meet or exceed thresholds for the implementation of four different types of mitigation measures.

None of the crash hotspots had a high enough concentration of reported crashes to meet or exceed any of the four thresholds for different types and combinations of mitigation measures (see previous section) (see also Table 12). However, seven out of the twelve carcass hotspots met or exceeded at least one of these thresholds (see also Table 13).

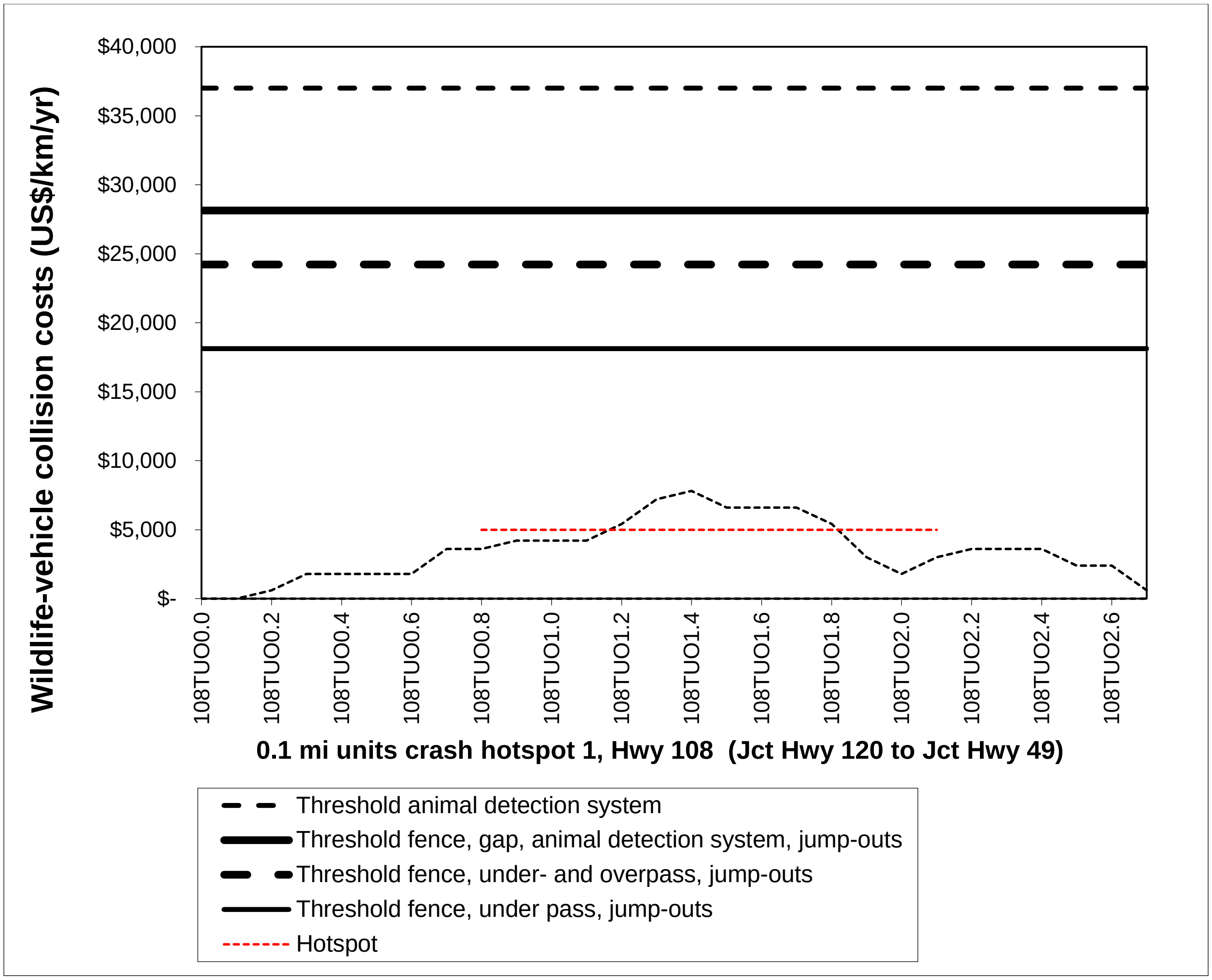

Figure 30: Hwy 108 from the Jct with Hwy 120 (left side of graph) to the Jct with Hwy 49 (right side of graph) around crash hotspot 1. The costs (jagged line, in 2007 US$) associated with deer-vehicle collisions per year (annual average based on crash data), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mile (160.9 m) long road unit concerned and adjacent units were summed to estimate the costs per kilometer. The dotted red line indicates the road section(s) identified as hotspot(s).

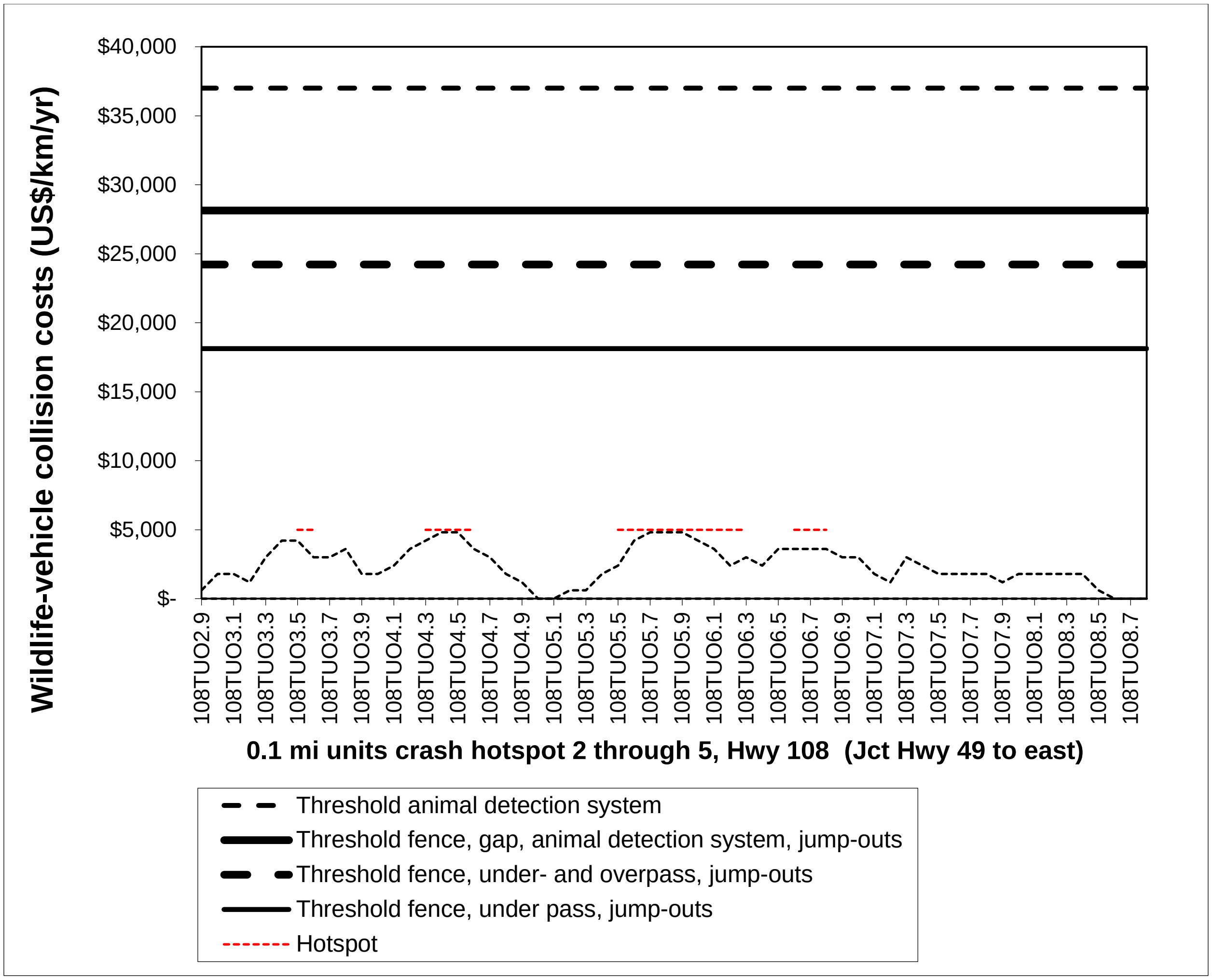

Figure 31: Hwy 108 from the Jct with Hwy 49 (left side of graph) to the east (right side of graph) around crash hotspots 2 through 5. The costs (jagged line, in 2007 US$) associated with deer-vehicle collisions per year (annual average based on crash data), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mile (160.9 m) long road unit concerned and adjacent units were summed to estimate the costs per kilometer. The dotted red line indicates the road section(s) identified as hotspot(s).

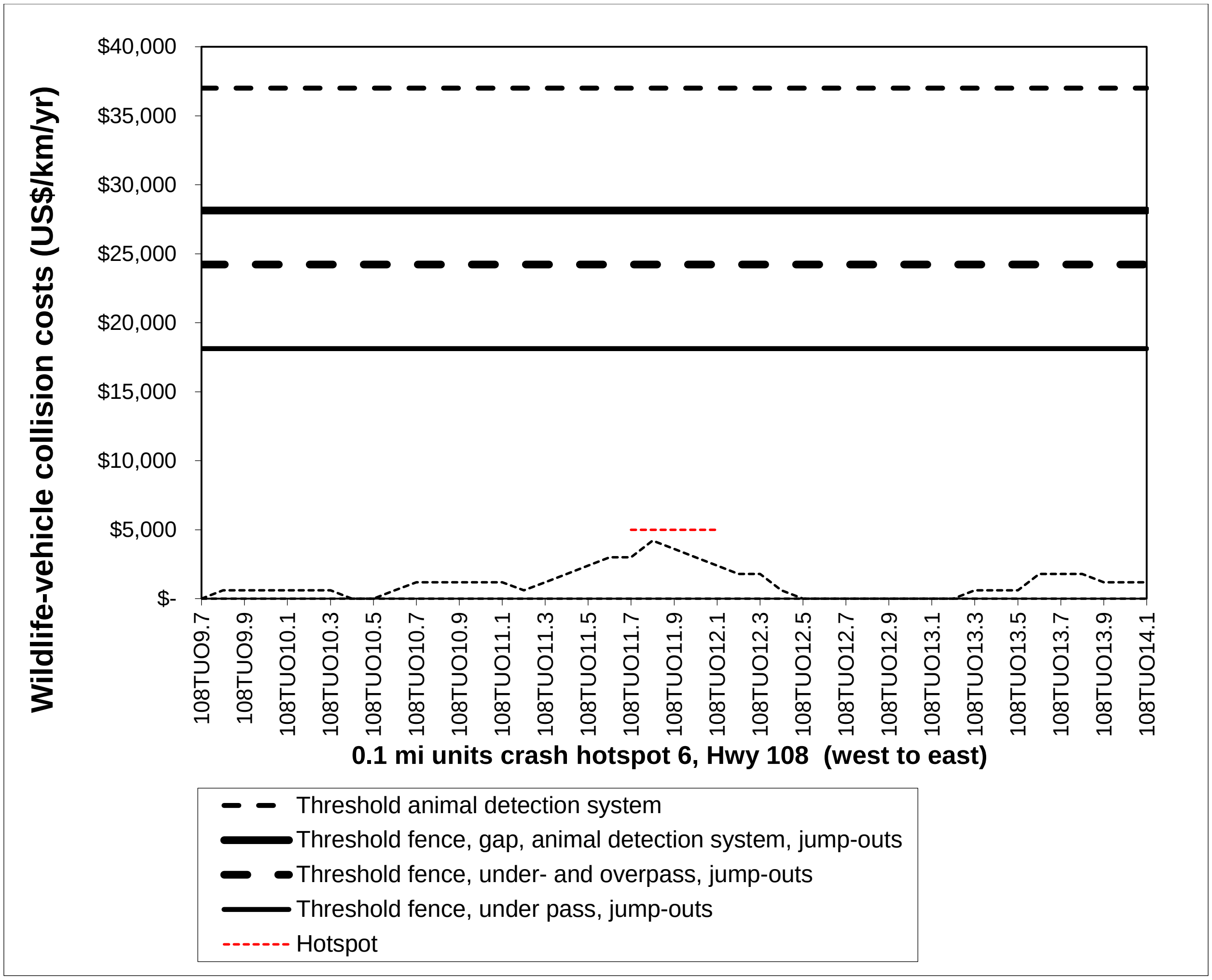

Figure 32: Hwy 108 from west (left side of graph) to east (right side of graph) around crash hotspot 6. The costs (jagged line, in 2007 US$) associated with deer-vehicle collisions per year (annual average based on crash data), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mile (160.9 m) long road unit concerned and adjacent units were summed to estimate the costs per kilometer. The dotted red line indicates the road section(s) identified as hotspot(s).

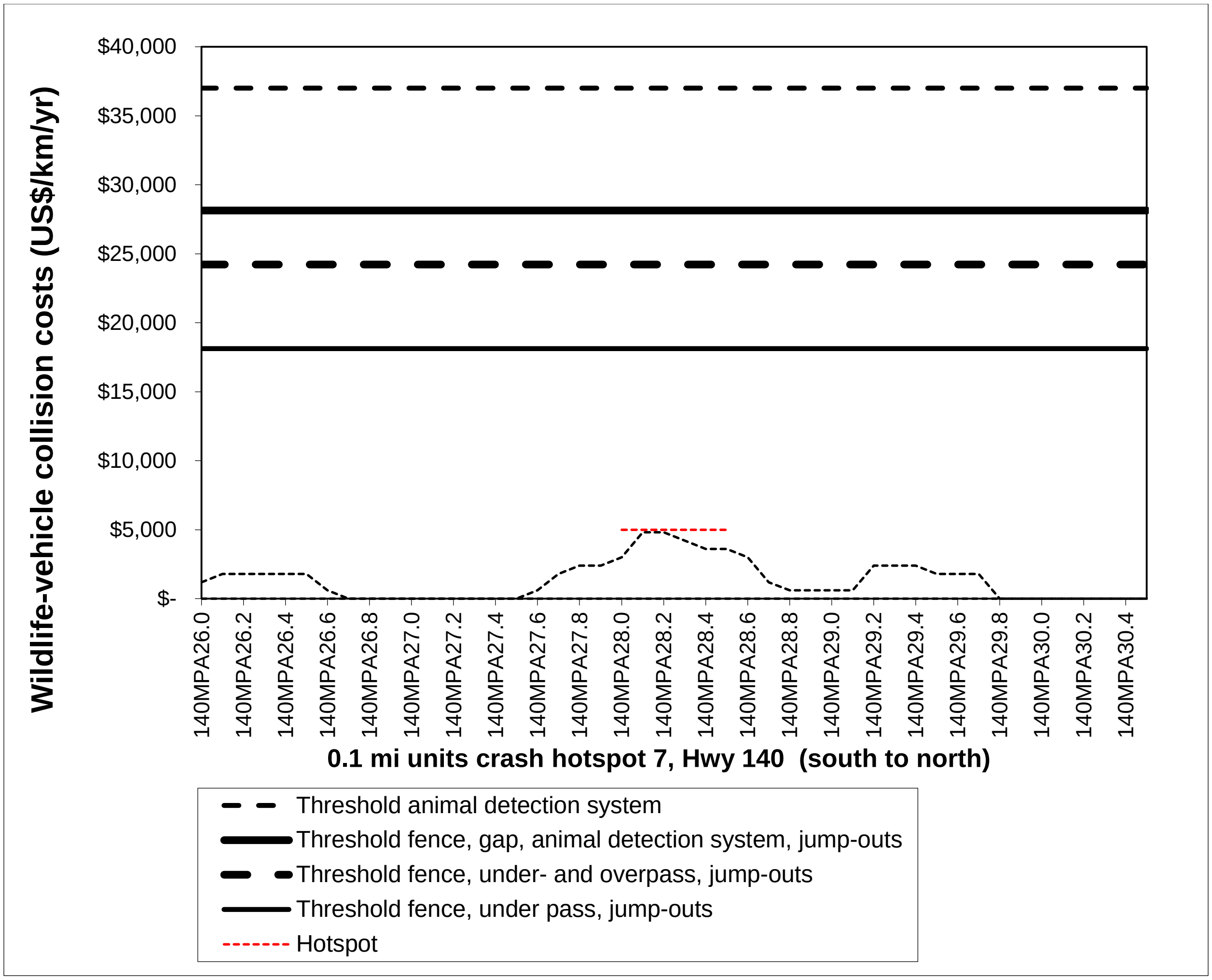

Figure 33: Hwy 140 from south (left side of graph) to north (right side of graph) around crash hotspot 7. The costs (jagged line, in 2007 US$) associated with deer-vehicle collisions per year (annual average based on crash data), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mile (160.9 m) long road unit concerned and adjacent units were summed to estimate the costs per kilometer. The dotted red line indicates the road section(s) identified as hotspot(s).

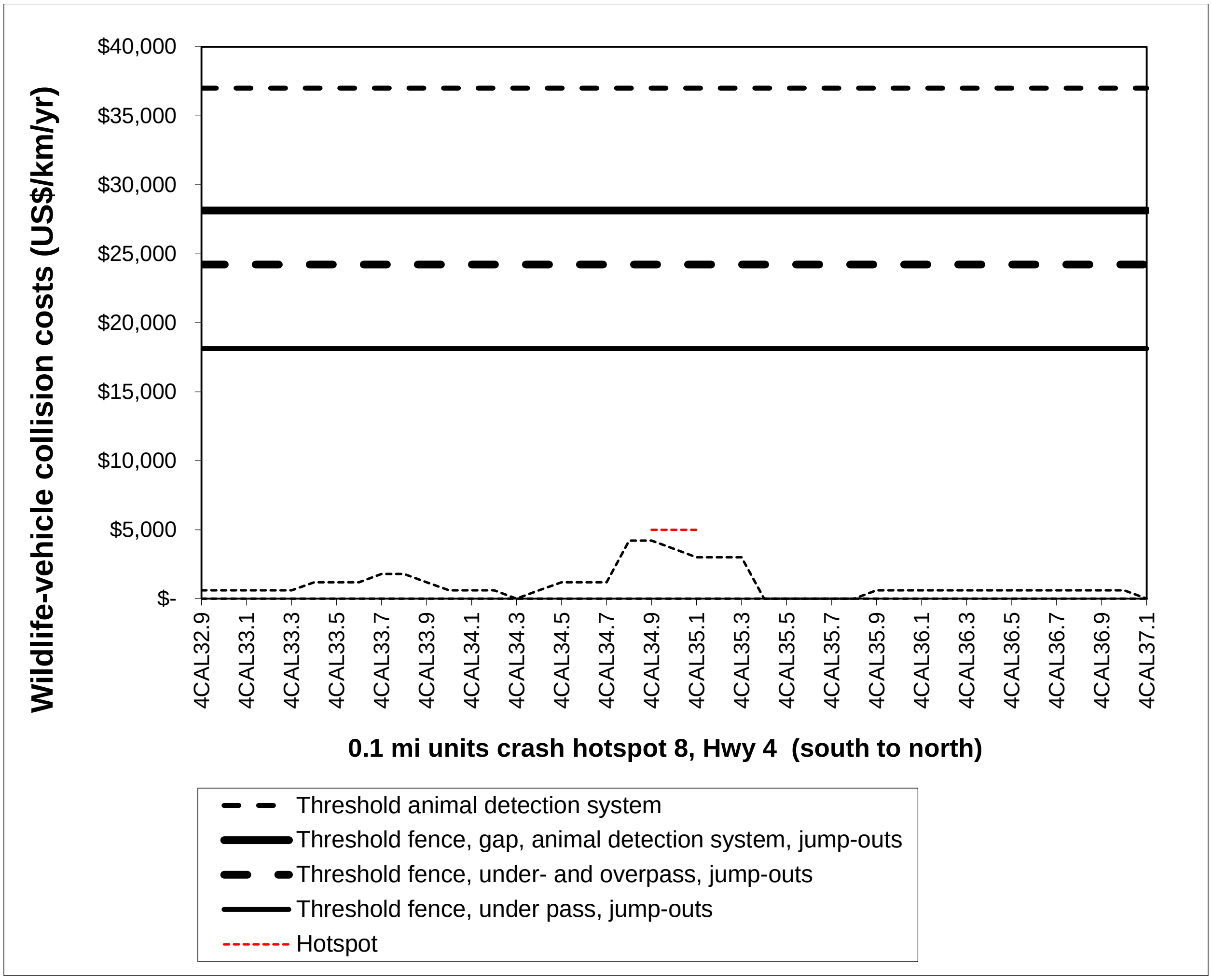

Figure 34: Hwy 4 from south (left side of graph) to north (right side of graph) around crash hotspot 8. The costs (jagged line, in 2007 US$) associated with deer-vehicle collisions per year (annual average based on crash data), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mile (160.9 m) long road unit concerned and adjacent units were summed to estimate the costs per kilometer. The dotted red line indicates the road section(s) identified as hotspot(s).

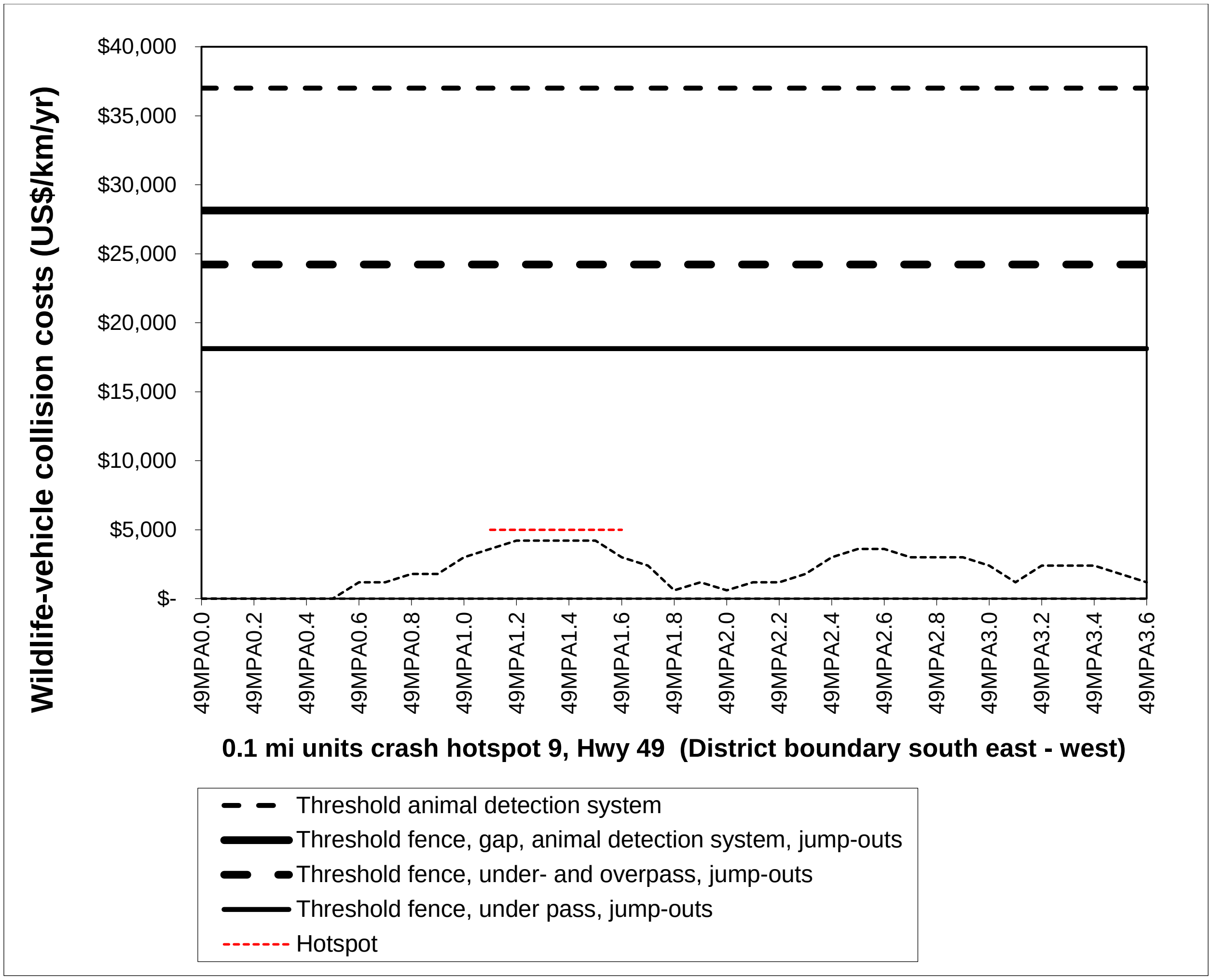

Figure 35: Hwy 49 from district boundary south east (left side of graph) to west (right side of graph) around crash hotspot 9. The costs (jagged line, in 2007 US$) associated with deer-vehicle collisions per year (annual average based on crash data), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mile (160.9 m) long road unit concerned and adjacent units were summed to estimate the costs per kilometer. The dotted red line indicates the road section(s) identified as hotspot(s).

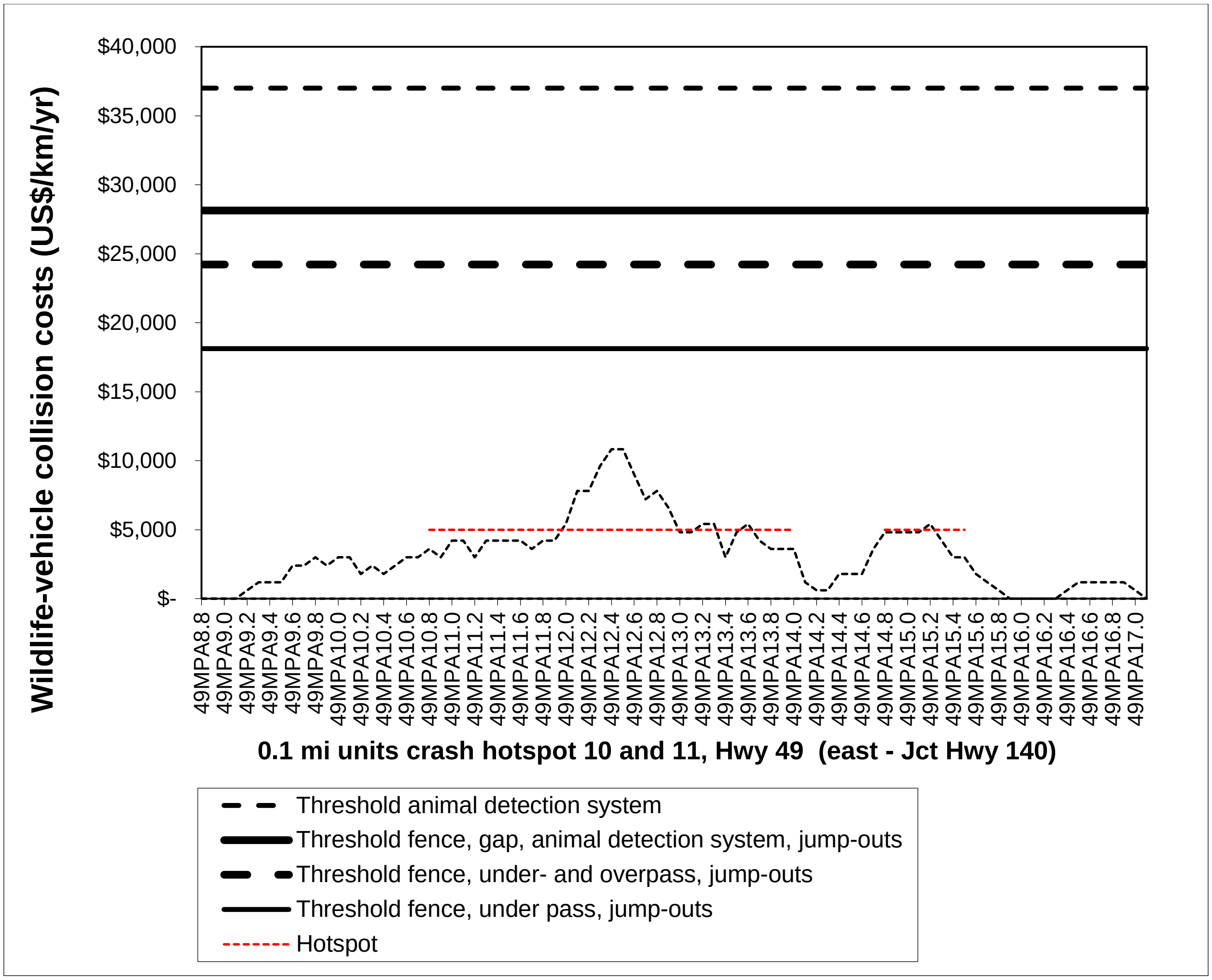

Figure 36: Hwy 49 from east (left side of graph) to Jct with Hwy 140 (right side of graph) around crash hotspot 10 and 11. The costs (jagged line, in 2007 US$) associated with deer-vehicle collisions per year (annual average based on crash data), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mile (160.9 m) long road unit concerned and adjacent units were summed to estimate the costs per kilometer. The dotted red line indicates the road section(s) identified as hotspot(s).

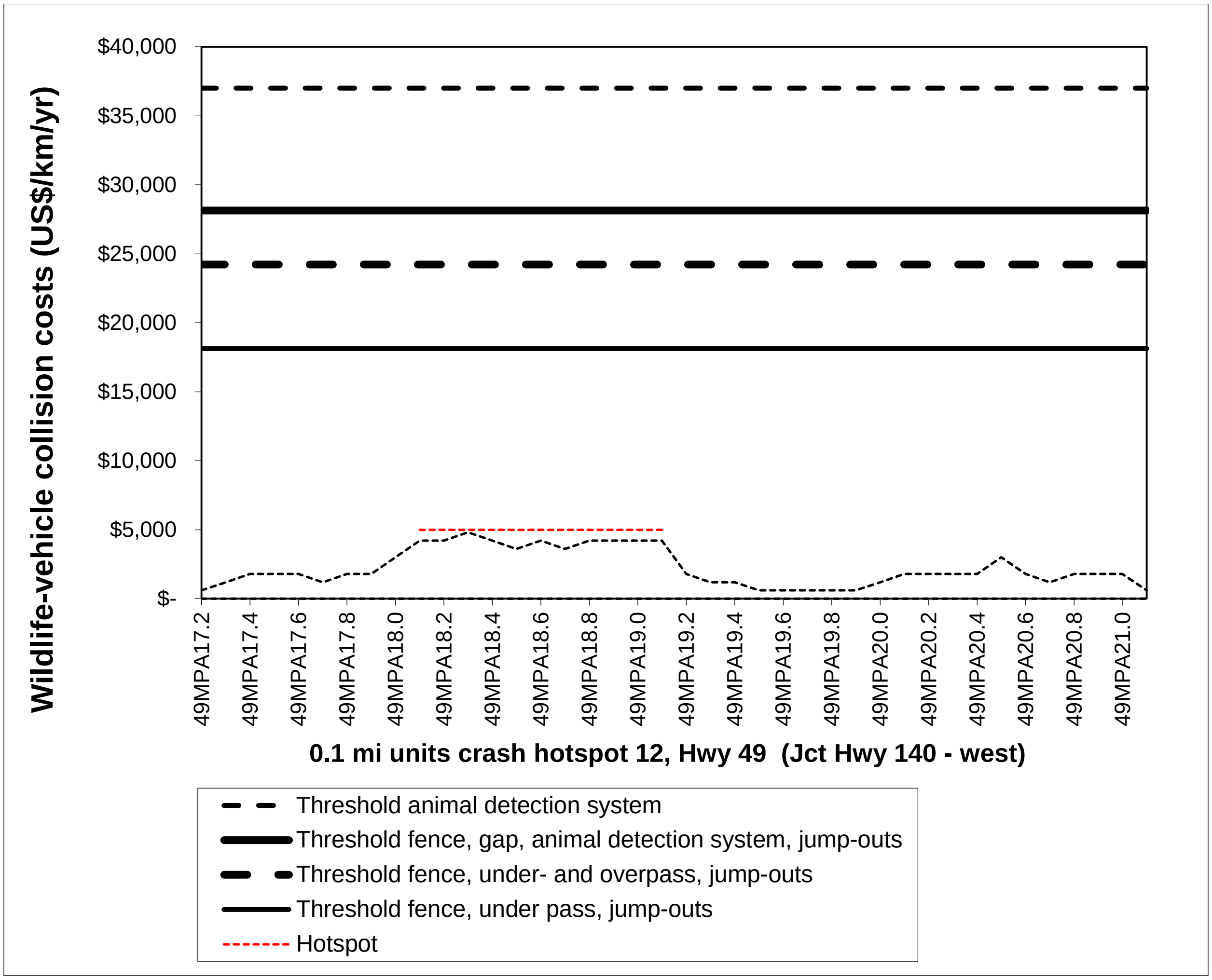

Figure 37: Hwy 49 from Jct with Hwy 140 (left side of graph) to west (right side of graph) around crash hotspot 12. The costs (jagged line, in 2007 US$) associated with deer-vehicle collisions per year (annual average based on crash data), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mile (160.9 m) long road unit concerned and adjacent units were summed to estimate the costs per kilometer. The dotted red line indicates the road section(s) identified as hotspot(s).

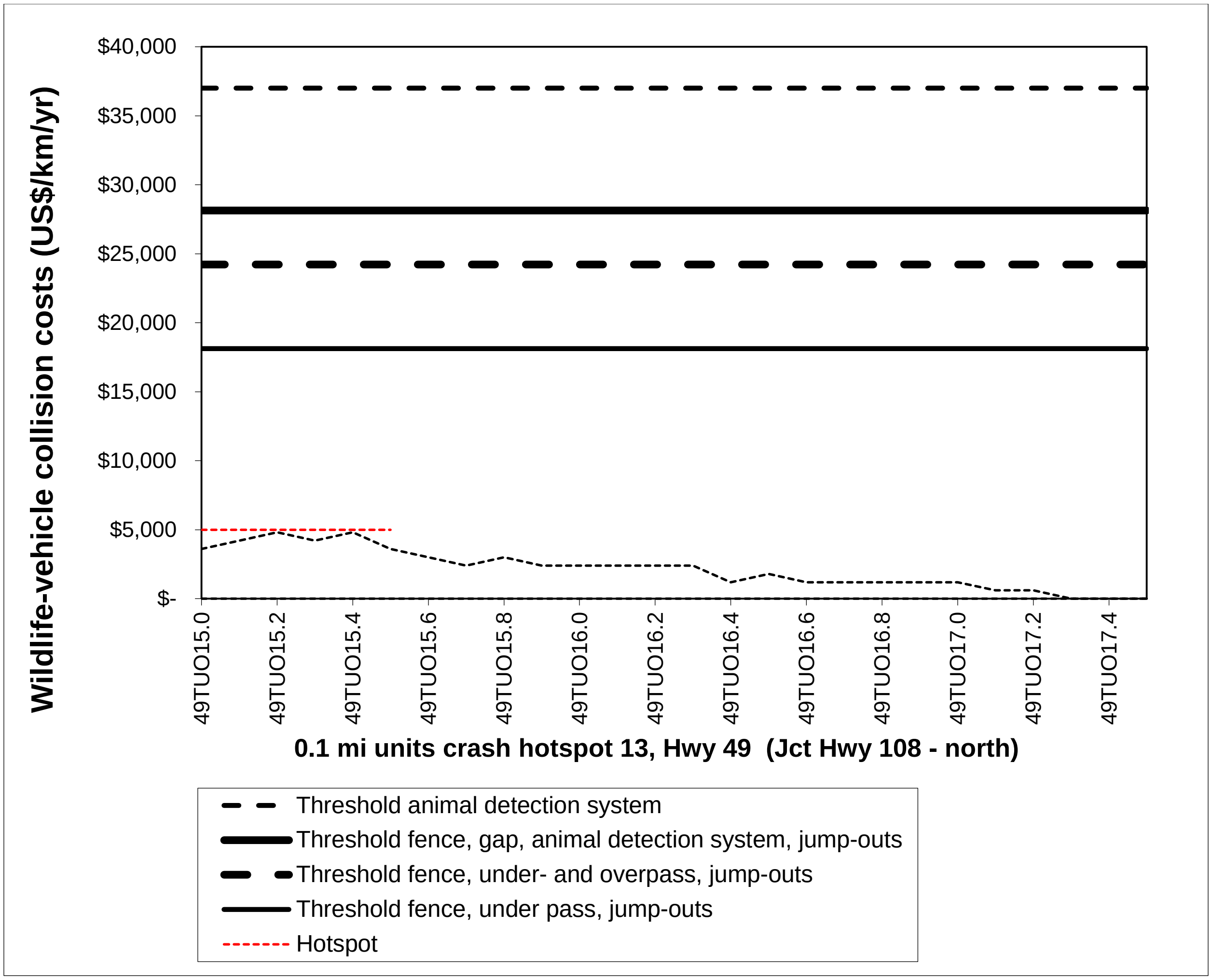

Figure 38: Hwy 49 from Jct with Hwy 108 (left side of graph) to north (right side of graph) around crash hotspot 13. The costs (jagged line, in 2007 US$) associated with deer-vehicle collisions per year (annual average based on crash data), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mile (160.9 m) long road unit concerned and adjacent units were summed to estimate the costs per kilometer. The dotted red line indicates the road section(s) identified as hotspot(s).

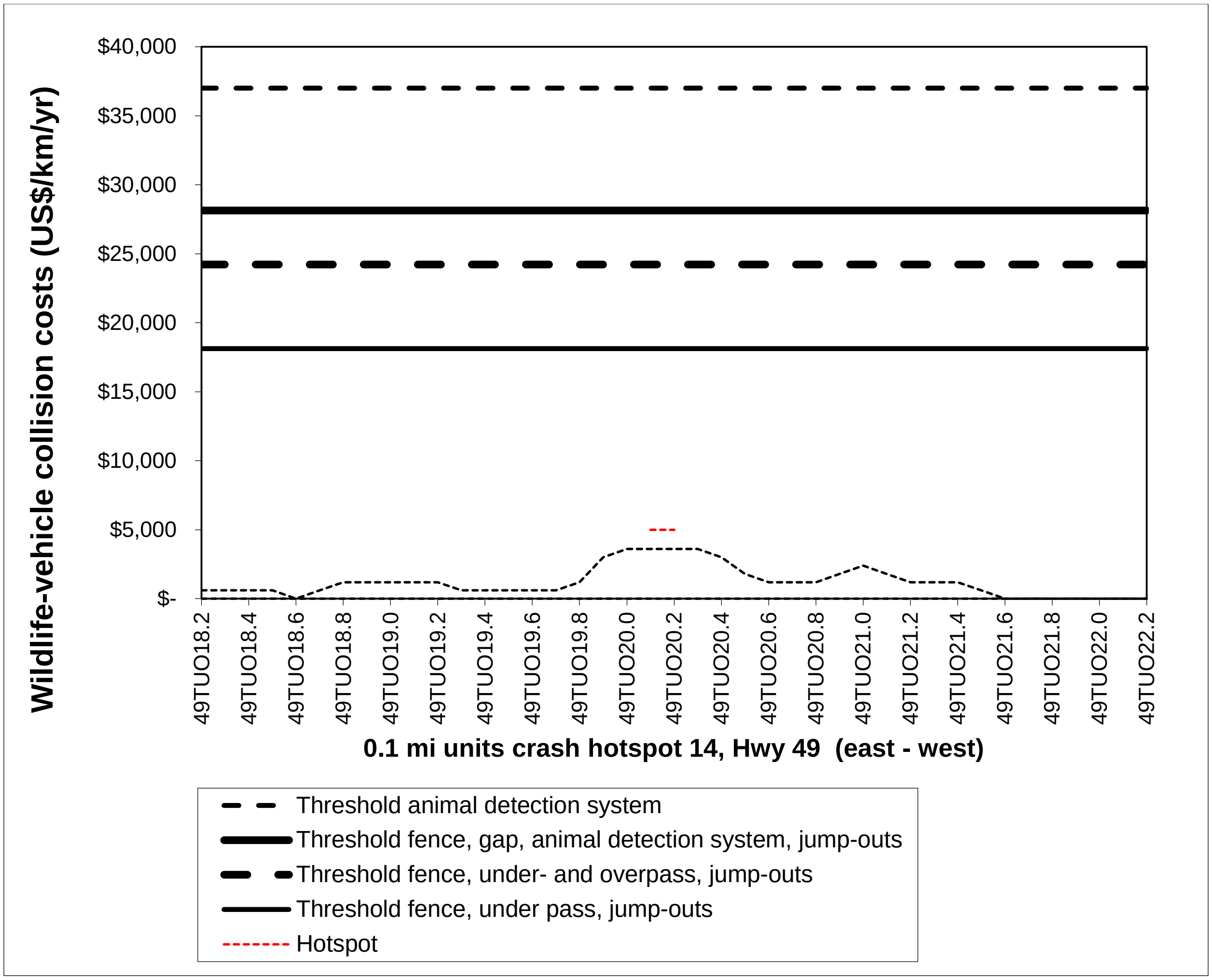

Figure 39: Hwy 49 from east (left side of graph) to west (right side of graph) around crash hotspot 14. The costs (jagged line, in 2007 US$) associated with deer-vehicle collisions per year (annual average based on crash data), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mile (160.9 m) long road unit concerned and adjacent units were summed to estimate the costs per kilometer. The dotted red line indicates the road section(s) identified as hotspot(s).

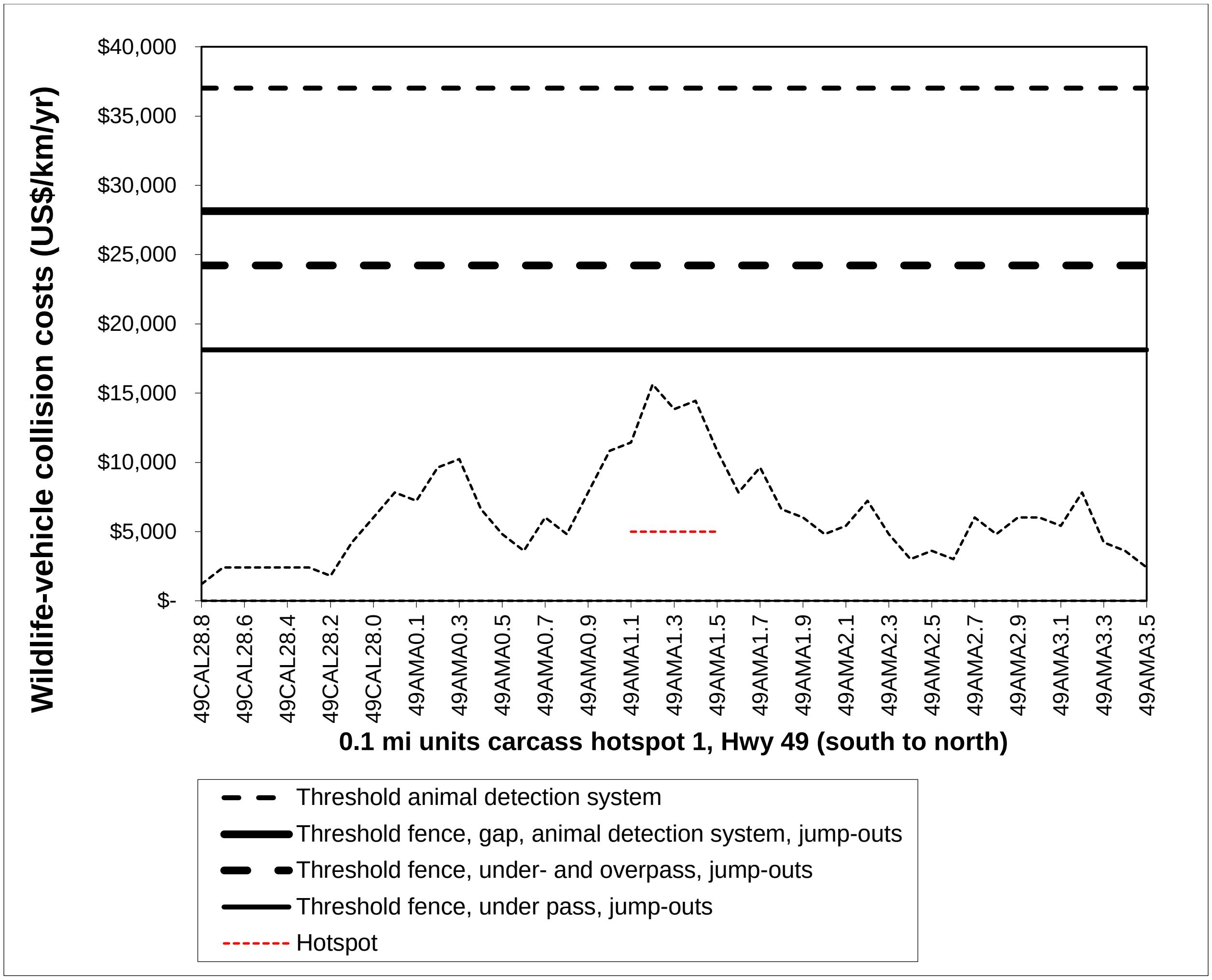

Figure 40: Hwy 49 from south (left side of graph) to north (right side of graph) around carcass hotspot 1. The costs (jagged line, in 2007 US$) associated with deer-vehicle collisions per year (annual average based on crash data), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mile (160.9 m) long road unit concerned and adjacent units were summed to estimate the costs per kilometer. The dotted red line indicates the road section(s) identified as hotspot(s).

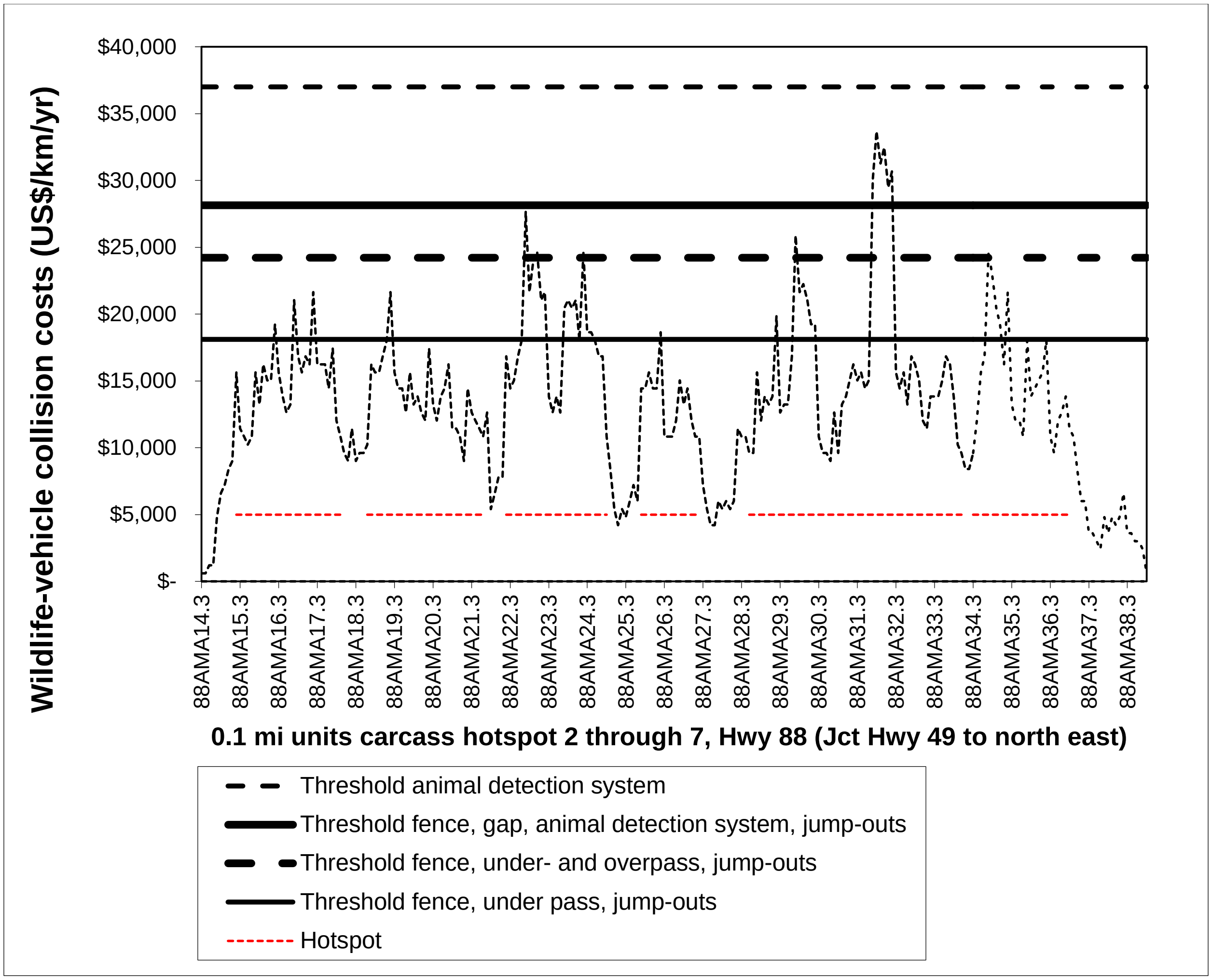

Figure 41: Hwy 88 from Jct Hwy 49 (left side of graph) to north east (right side of graph) around carcass hotspots 2 through 7. The costs (jagged line, in 2007 US$) associated with deer-vehicle collisions per year (annual average based on crash data), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mile (160.9 m) long road unit concerned and adjacent units were summed to estimate the costs per kilometer. The dotted red line indicates the road section(s) identified as hotspot(s).

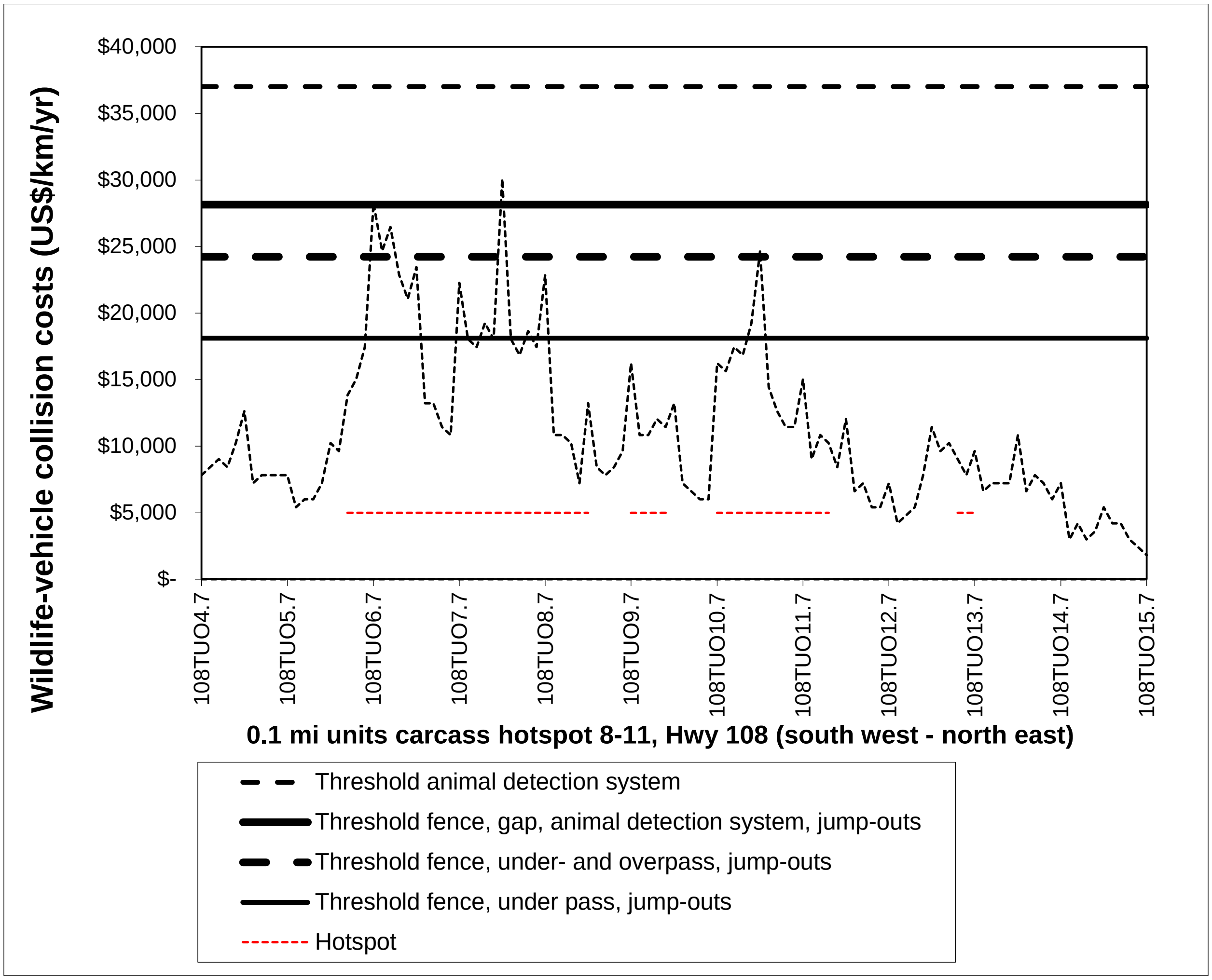

Figure 42: Hwy 108 from south west (left side of graph) to north east (right side of graph) around carcass hotspots 8 through 11. The costs (jagged line, in 2007 US$) associated with deer-vehicle collisions per year (annual average based on crash data), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mile (160.9 m) long road unit concerned and adjacent units were summed to estimate the costs per kilometer. The dotted red line indicates the road section(s) identified as hotspot(s).

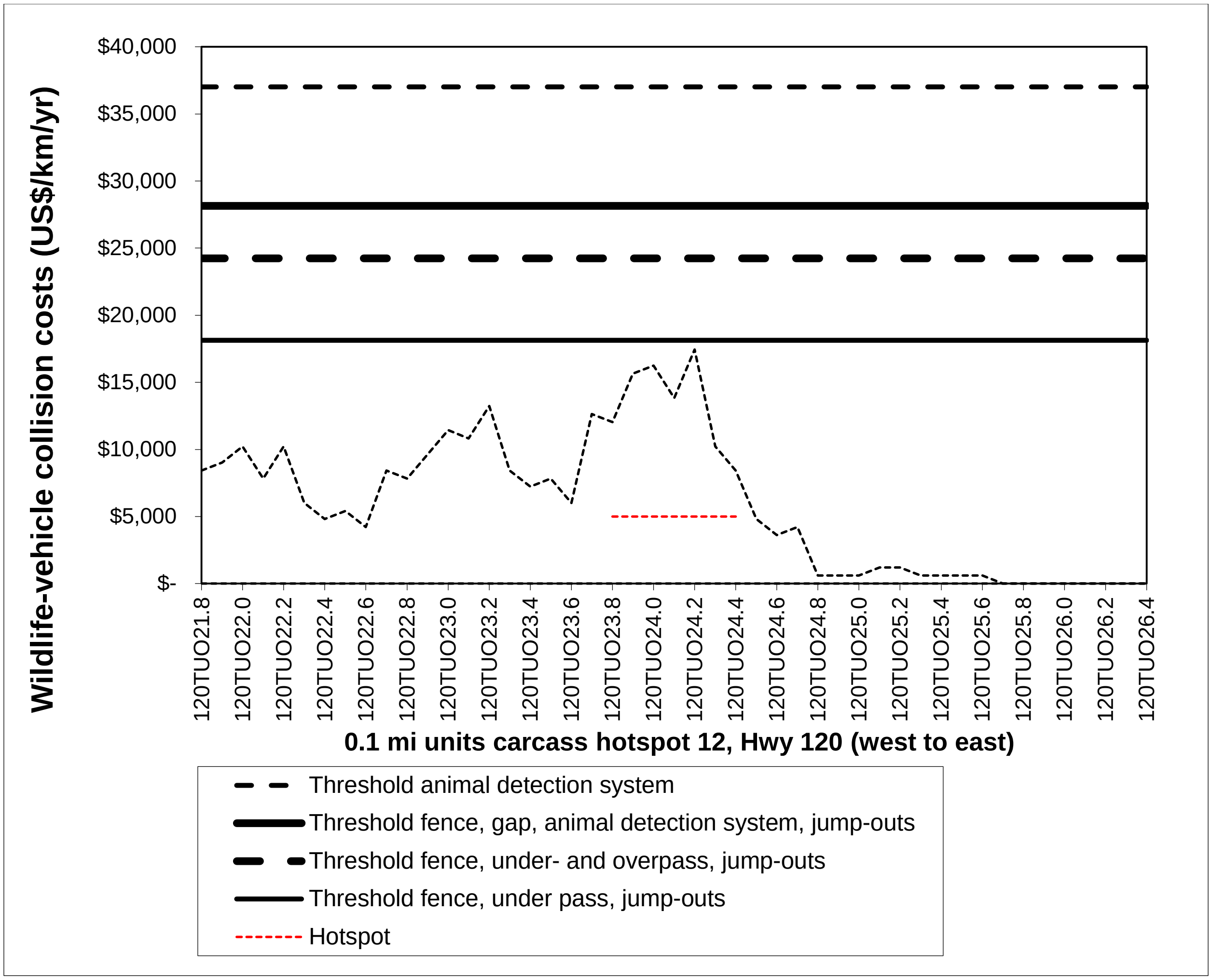

Figure 43: Hwy 120 from west (left side of graph) to east (right side of graph) around carcass hotspot 12. The costs (jagged line, in 2007 US$) associated with deer-vehicle collisions per year (annual average based on crash data), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mile (160.9 m) long road unit concerned and adjacent units were summed to estimate the costs per kilometer. The dotted red line indicates the road section(s) identified as hotspot(s).

5.4. Ranking Hotspots Based on Economic Parameters

Tables 12 and 13 list the length of the crash and carcass hotspots, the number of thresholds met or exceeded for the four different types and combinations of mitigation measures, the peak costs associated with deer crashes in the individual crash hotspots, the sum of the costs associated with deer crashes in the individual hotspots, and the average costs (per 0.1 mi) associated with deer crashes in the individual hotspots. The researchers first ranked the hotspots based on the number of thresholds exceeded. In case of a tie, the sum of the costs for a hotspot and the average cost per 0.1 mi were also used to rank the hotspots. The ranking is used later (Chapter 6) to prioritize the hotspots.

Table 12: The length of the road segments with the crash hotspots, the number of thresholds met or exceeded for the four different types and combinations of mitigation measures, the peak costs associated with deer crashes in the individual crash hotspots, the sum of the costs associated with deer crashes in the individual hotspots, the average costs (per 0.1 mi) associated with deer crashes in the individual hotspots, and the ranking based on the economic parameters.

Hotspot ID	Length (mi)	Number of thresholds exceeded	Peak value 0.1 mi segment ($)	Sum costs crashes ($)	Average cost crashes ($/0.1 mi)	Ranking economics
Crash 1	1.4	0	$7,820	$69,779	$4,984	2
Crash 2	0.2	0	$4,211	$7,219	$3,609	12
Crash 3	0.4	0	$4,812	$17,445	$4,361	8
Crash 4	0.8	0	$4,812	$31,882	$3,985	5
Crash 5	0.3	0	$3,609	$10,828	$3,609	13
Crash 6	0.5	0	$4,211	$16,242	$3,248	10
Crash 7	0.6	0	$4,812	$24,062	$4,010	7
Crash 8	0.3	0	$4,211	$10,828	$3,609	11
Crash 9	0.6	0	$4,211	$23,460	$3,910	9
Crash 10	3.3	0	$10,828	$178,659	$5,414	1
Crash 11	0.8	0	$5,414	$34,890	$4,361	3
Crash 12	1.1	0	$4,812	$45,717	$4,156	4
Crash 13	0.6	0	$4,812	$25,265	$4,211	6
Crash 14	0.1	0	$3,609	$3,609	$3,609	14

Table 13: The length of the road segments with the carcass hotspots, the number of thresholds met or exceeded for the four different types and combinations of mitigation measures, the peak costs associated with deer carcasses in the individual crash hotspots, the sum of the costs associated with deer carcasses in the individual hotspots, the average costs (per 0.1 mi) associated with deer carcasses in the individual hotspots, and the ranking based on the economic parameters.

Hotspot ID	Length (mi)	Number of thresholds exceeded	Peak value 0.1 mi segment ($)	Sum costs carcasses ($)	Average cost carcasses ($/0.1 mi)	Ranking economics
Carcass 1	0.5	0	$15,640	$66,170	$13,234	10
Carcass 2	2.9	1	$21,656	$430,105	$14,831	6
Carcass 3	3.1	1	$21,656	$430,105	$13,874	7
Carcass 4	2.7	2	$27,671	$500,486	$18,537	3
Carcass 5	1.6	0	$15,640	$212,947	$13,309	8
Carcass 6	5.6	3	$33,687	$914,349	$16,328	1
Carcass 7	2.6	2	$24,663	$392,809	$15,108	4
Carcass 8	2.9	3	$30,077	$513,118	$17,694	2
Carcass 9	0.5	0	$16,242	$61,358	$12,272	11
Carcass 10	1.4	2	$24,663	$205,127	$14,652	5
Carcass 11	0.3	0	$9,625	$26,468	$8,823	12
Carcass 12	0.7	0	$17,445	$93,841	$13,406	9

5.5. Comparison with Caltans' Traffic Safety Index

The Traffic Safety Index is a tool used by Caltrans to evaluate the safety benefits of highway improvement projects. The index is expressed as the costs saved through increased safety as a percentage of the investments in the highway improvement (HSIP, 2008):

Index (%) = $((C_{\text{no improvement}} - C_{\text{improvement}})/ I)*100$

$C_{\text{no improvement}}$ = Cost of collisions that may occur on the highway segment if improvement project is not implemented.
$C_{\text{improvement}}$ = Cost of collisions that are expected to occur on the highway segment if improvement project is implemented
I = Costs associated with the improvement

In general, statewide averages are used to calculate the costs associated with collisions, assuming the proportion of accidents that involve human fatalities, human injuries, or property-damage-only is similar in the project area and the state as a whole.

The above approach is also possible for deer crash or deer carcass data. The costs associated with the average deer vehicle collision are known and include costs associated with human fatalities, human injuries, and vehicle repair costs (Huijser et al., 2009). The costs associated with the "improvement" (i.e. the mitigation measures) are also known or they can be estimated for a specific project based on bids.

There may be the following differences though, with the cost-benefit analysis in the previous sections:

1. Wildlife-vehicle collisions are notoriously underestimated if they are estimated based on crash data only. Carcass removal data suffer less from this problem, but the underestimation is reduced. If the Traffic Safety Index method is used to investigate the potential financial benefits of implementing mitigation measures aimed at reducing large mammal-vehicle collisions, implementation may not or rarely happen if only wildlife crash data are used. Wildlife carcass removal data may have to be used instead, which is quite possible to do.
2. Mitigation projects aimed at reducing wildlife-vehicle collisions are almost never at a "spot" (e.g. an intersection); they are more likely to occur along a road section (several tens of miles or multiple miles long). This is not necessarily a problem as the Traffic Safety Index can relate to a spot or a road section.

As an example the researchers calculated the Traffic Safety Index for two hotspots (carcass hotspot 6 and 4) (Table 14). While Carcass hotspot 6 ranked highest (see Table 13) carcass hotspot 4 had a much higher traffic safety index (Table 14) because the average number of collisions per km was higher than in carcass hotspot 6.

Table 14: Examples calculation Traffic Safety Index. All parameters were standardized to per kilometer per year. Costs of deer-vehicle collisions and mitigation measures were based on Huijser et al. (2009). The mitigation measure evaluated here is large mammal underpass (one per 2 km) in combination with large mammal fencing and jump-outs (see Huijser et al. (2009).

	Carcass 6	Carcass 4
Length hotspot (mi)	5.60	0.8
Historical collisions (n/year)	23.54	12.82
Historical collisions (n/km/year)	2.61	9.96
Costs average collision ($)	$6,617	$6,617
Costs collisions ($/year)	$155,764	$84,830
Cost collisions ($/km/year)	$17,287	$65,903
Expected reduction with mitigation (%)	86	86
Costs collisions after mitigation ($/km/year)	$2,420	$9,226
Mitigation costs (3% discounting) ($/km/year)	$18,123	$18,123
Traffic safety index (%)	82.03	312.73

5.6. Discussion and Conclusions

None of the crash hotspots had road sections where the economic threshold values for the four mitigation measures were met. However, seven out of the twelve carcass hotspots did meet or exceed at least one of the thresholds. While the researchers strongly advise to use the cost-benefit analyses as a decision support tool they also urge users to recognize that these analyses are only one of the factors that may or should be considered in the decision making process. Human safety should perhaps not only be evaluated in dollar values and passive use values for wildlife are currently not included in the cost-benefit analyses.

The cost-benefit analyses were based on crash data for the crash hotspots and carcass data for the carcass hotspots. For the data used in the analyses crash data were only 24.8% of the carcass data; in Caltrans District 10 crash data are underreported compared to carcass data, similar to many areas. This makes it more likely that thresholds will be met at carcass hotspots using carcass data than at crash hotspots using crash data. To minimize the effect of underestimating the cost associated with deer-vehicle collisions, one may choose to multiply the crash data with a factor 4.03 as deer crash data were only 24.8% of the total number of recorded deer carcasses in Caltrans District 10. For carcass hotspots it is also important to realize that not all carcasses are reported (Tardif and Associates Inc. 2003, Sielecki 2004, Riley & Marcoux 2006, Donaldson & Lafon 2008). Carcass data depend on forms filled out by road maintenance crews that pick up carcasses and dispose of them (Huijser et al., 2007). Animals that die outside of the right-of-way or carcasses that may not be in sight of the drivers may not be picked up and remain unrecorded. Thus even carcass removal data should be regarded as a minimum count rather than an absolute count of the number of large animal-vehicle collisions that occur.

The costs for the average deer-vehicle collision are mostly based on collisions reported to the insurance industry or to law enforcement agencies (Huijser et al., 2009), and one could argue that unreported collisions are likely to be less costly than reported collisions. Therefore, by using carcass data we may have overestimated the average costs of a collision with a deer. On the other hand, insurance industry reports and police accident reports may underestimate ungulate–vehicle collisions by about 50% (Tardif & Associates Inc. 2003, Riley and Marcoux 2006), and law enforcement agencies may only record a fraction (14%) of the deer–vehicle collisions reported to the insurance industry (Donaldson and Lafon 2008). Furthermore, in most states and provinces in the United States and Canada, no accident report is filled out by law enforcement agencies if the estimated vehicle damage is less than US$1000 (Huijser et al. 2007). The most conservative approach would be to only include collisions that were reported to the insurance industry or law enforcement agencies and screen the data for potential duplicates. However, based on the studies cited above, it is clear that such an approach may lead to a serious underestimation of the actual costs of collisions with large ungulates, and one may choose to include carcass reports, recognizing that although this may overestimate the average costs associated with a deer–vehicle collision, it may still underestimate the actual number of ungulate–vehicle collisions by about 50%.

The cost-benefit analyses presented in this chapter are based on a four lane divided highway. However, the highways at the hotspots in Caltrans District 10 are typically two lanes. If mitigation measures are put in place without widening the road then the thresholds are likely lower than projected in this chapter; there are likely more and longer road sections where the costs associated with wildlife-vehicle collisions meet or exceed the thresholds. If the road is completely reconstructed and widened at the same the mitigation measures are installed there can be overall cost savings, but the costs for the crossing structures will increase compared to those for a two lane road.

This cost-benefit analysis is relatively conservative and does not include passive use values. For a full understanding what is and what is not included in the cost-benefit analyses and how the analyses were conducted please see Huijser et al. (2009). It is also important to know that the costs and benefits are expressed in 2007 US$. Since the costs associated with deer-vehicle collisions and with mitigation measures change continuously and can even vary substantially depending on the geographic region, the cost-benefit analyses should be regarded as indicative. The researchers would also like to point out that the cost-benefit analyses does not include all parameters that should be considered when making a decision on the implementation of potential mitigation measures. The researchers strongly advise to use the cost-benefit analyses as a decision support tool but also urge users to recognize that it is only one of the factors that may or should be considered in the decision making process. Examples of other factors that should be considered are the need for different wildlife species to have a certain degree of connectivity across the landscape, including roads, so that their population can be expected to persist in the region over a certain amount of time.

Finally, locations where animal-vehicle collisions occur are not necessarily the same locations where animals are crossing the road successfully. Decisions on the types of mitigation measures, especially barriers, should not only be based on where carcasses are found, but data on successful crossings of the target species as well as other species should also be considered. It is considered good practice to not increase the barrier effect of a road (e.g. through wildlife fences) without also providing for safe crossing opportunities.

6. STEPWISE APPROACH: PRIORITIZE CRASH AND CARCASS HOTSPOTS BASED ON HUMAN SAFETY, NATURE CONSERVATION AND ECONOMIC PARAMETERS

The crash and carcass hotspots and their rankings with regard to human safety (Chapter 3), nature conservation (Chapter 4) and economics (chapter 5) are shown in Table 15 and 16. Crash hotspot 10, 1, 11, 12, and 4 appear to rank the highest overall among the crash hotspots but none of the crash hotspots was located in a Natural Landscape Block or an Essential Connectivity Area. Carcass hotspots 4, 2, and 3 rank relatively high for human safety and economics while they are also located in an Essential Connectivity Area. Depending on whether the emphasis is on human safety, nature conservation or economics, one can select the crash and carcass hotspots that may be considered first for mitigation. However, it is important to remember that all crash and carcass hotspots listed already have a relatively high concentration of deer-vehicle crashes or deer carcasses. The ranking of the crash and carcass hotspots listed in the tables below is simply to help prioritize where mitigation has the highest returns for human safety, nature conservation and monetary investments.

Table 15: The length of the road segments with the crash hotspots, the number of deer crashes reported in those hotspots, and the ranking for human safety. The ranking was based first on the sum of deer crashes in the individual hotspots, and, in case of a tie, also on the average number of deer crashes in a hotspot per 0.1 mi.

Hotspot ID	Length (mi)	Ranking human safety	Ranking nature conservation	Ranking economics
Crash 1	1.4	2	n/a	2
Crash 2	0.2	12	n/a	12
Crash 3	0.4	8	n/a	8
Crash 4	0.8	5	n/a	5
Crash 5	0.3	11	n/a	13
Crash 6	0.5	10	n/a	10
Crash 7	0.6	6*	n/a	7
Crash 8	0.3	9	n/a	11
Crash 9	0.6	7	n/a	9
Crash 10	3.3	1	n/a	1
Crash 11	0.8	4	n/a	3
Crash 12	1.1	3	n/a	4
Crash 13	0.6	6*	n/a	6
Crash 14	0.1	13	n/a	14

***= tie**

Table 16: The length of the road segments with the carcass hotspots, the number of deer carcasses reported in those hotspots, and the ranking for human safety. The ranking was based first on the sum of deer carcasses the individual hotspots, and, in case of a tie, also on the average number of deer carcasses in a hotspot per 0.1 mi.

Hotspot ID	Length (mi)	Ranking human safety	Ranking nature conservation	Ranking economics
Carcass 1	0.5	10	1*	10
Carcass 2	2.9	5	1*	6
Carcass 3	3.1	4	1*	7
Carcass 4	2.7	3	1*	3
Carcass 5	1.6	7	n/a	8
Carcass 6	5.6	1	n/a	1
Carcass 7	2.6	6	n/a	4
Carcass 8	2.9	2	n/a	2
Carcass 9	0.5	11	n/a	11
Carcass 10	1.4	8	n/a	5
Carcass 11	0.3	12	n/a	12
Carcass 12	0.7	9	n/a	9

***= tie**

7. STEPWISE APPROACH: MITIGATION RECOMMENDATIONS

7.1. Introduction

This chapter contains descriptions of potential mitigation measures at the crash and carcass hotspots, should Caltrans or other stakeholders choose to implement mitigation measures. The approach for this particular project is limited to mitigation, rather than also including options for avoidance and compensation (see Chapter 2). For this particular project the approach is also restricted to mitigation measures aimed at:

- Improving human safety and reducing direct wildlife mortality through reducing deer-vehicle collisions.
- Keeping the highways permeable for wildlife in general despite the presence of the highway, traffic and potential mitigation measures aimed at keeping deer off the road (e.g. wildlife fencing).

There are many publications that include an overview of mitigation measures aimed at reducing collisions with large mammals and at providing safe crossing opportunities for wildlife (see e.g. Huijser et al. 2008; Clevenger & Huijser, 2011). We refer to these publications for a general overview. In essence, wildlife fencing is one of the most effective ways to keep large animals off the road; collisions with large mammals are typically reduced by 79-99%. It is considered bad practice though to increase the barrier effect of roads and traffic for wildlife without also providing for sufficient safe crossing opportunities. For relatively high traffic volume (>15,000 vehicles/day) a physical separation of vehicles and wildlife is almost always desirable. This can be achieved by providing underpasses and overpasses. At relatively low traffic volume (e.g. < 3,000 vehicles/day) one could consider at grade crossing opportunities (basically a gap in the fence on both sides of the road), but additional measures including advisory or mandatory speed limit reduction and traffic calming measures (e.g. speed bumps or bulb outs), and measures that encourage the animals to cross the road straight (e.g. wildlife guards or electric mats embedded in the road on either end of the gap) may be important to achieving a substantial reduction in large mammal-vehicle collisions. Animal detection systems may also be used at gaps in fences, but these systems are still mostly experimental rather than a robust mitigation measure that can be expected to function as intended immediately after installation. Animal detection systems can also be implemented as a stand-alone mitigation measure and can also substantially reduce collisions with large mammals (range 58-99%). For this project only wildlife fencing in combination with wildlife underpasses and wildlife overpasses and animal detection systems are discussed as potential mitigation measures.

7.2. Wildlife Fencing

For large ungulates in North America 8 ft (2.4 m) high mesh wire fencing with wooden posts is the most frequently used fence type to keep animal species such as white-tailed deer, mule deer, elk, and moose off the road. For species that can climb a fence with large meshes or wooden posts (e.g. black bears, mountain lions), smaller mesh sizes, metal posts, and overhangs at the top of the fence are sometimes used. To discourage animals from digging under the fence (e.g.

coyotes) sometimes dig barriers are installed. See Huijser et al. (2008) and Clevenger and Huijser (2011) for details.

Wildlife fencing is most effective if implemented over relatively long distances (e.g. at least several miles or kilometers) (e.g. Gagnon et al., 2007). If no or relatively short fencing is provided animals that approach the road section at or near the safe crossing opportunity may simply walk to the fence end and cross at grade. This means that relatively short sections of wildlife fencing (e.g. up to a few miles) are less effective and more variable (perhaps around 50-60% reduction) than long sections of wildlife fencing (e.g. dozens of miles long) in reducing wildlife-vehicle collisions (>80% reduction) (e.g. Clevenger et al., 2001). Short sections of wildlife fencing may partially relocate wildlife-vehicle collisions rather than substantially (>80% reduction) reduce them.

The wildlife fencing should at a minimum cover the full length of a hotspot on both sides of the road. However, if the fence stops at the end of a road section that has been identified as a hotspot, a substantial portion of the animals that would have crossed at the hotspot barely have to go out of their way to cross at grade at one of the two fence ends rather than through a safe crossing opportunity in the mitigated hotspot. This may then result in a slight shift in the location of a hotspot rather than a real and substantial reduction in wildlife-vehicle collisions. Therefore a buffer zone is recommended that extends from the two ends of a hotspot. The wildlife fencing continues in this buffer zone and makes it more “costly” for the animals to walk to a fence end and cross at grade. The length of the buffer zone should be based on the home range size of the target species. The average diameter of the home range of a mule deer may be about 2,400 m (see section 7.4). So, if a mule deer would have the center of its home range at the edge of a hotspot, it may still easily travel 1,200 m, suggesting that the buffer zone for mule deer should extend at least 1,200 m from the end of a hotspot. Safe crossing opportunities should be located in the actual hotspot, but if there is additional information of relatively large numbers of animals that cross the road successfully in the buffer zone, additional safe crossing opportunities may be considered in the buffer zone as well.

7.3. Safe Crossing Opportunities for Wildlife

The authors of this report distinguished seven different types of safe crossing opportunities for potential implementation on and along the roads in the study area (Table 17). Note that there are other types of crossing structures (e.g. for amphibians), but these are not included in this report because this report primarily focusses on large mammals and most amphibians and reptiles (i.e. snakes) are also able to pass through a standard the wildlife fence. Nonetheless, should amphibian crossing be installed, specific precast products are available that allow for soil and air temperature inside the tunnels that is similar to outside the tunnels. In addition, there is also specialized fencing (including plastic sheets) available that can be attached to a fence designed to keep large mammals off the road. Furthermore, structures that are suitable for large terrestrial mammals can also be made suitable for amphibians and reptiles. For example, if wet habitat is present or created on or nearby an overpass or underpass, amphibians and other semi-aquatic species are more likely to use the crossing opportunity. Similarly, aquatic or semi-aquatic species are likely to use a crossing opportunity if the underpass is combined with a stream or river crossing. Stream characteristics and stream dynamics must be carefully studied to ensure that the conditions inside the crossing structure are and remain similar to that of the stream up- and downstream of the structure. Such parameters include e.g. water velocity, variability in water velocity, erosion of substrate inside the crossing structure, or up- and downstream of the structure, and the implications of high and low water events, including debris and potential maintenance issues. If terrestrial animals are to use the underpass as well, a minimum path width of 0.5 m is recommended for small and medium mammals, and 2-3 m for large mammals (for both two lane and four lane highways) (Clevenger & Huijser, 2011). Furthermore, small mammals, amphibians and reptiles increase their use of wildlife underpasses and overpasses if cover (e.g. tree stumps, branches and rocks) is provided for continuous travel through or over the crossing structure. Nonetheless, one may choose to provide additional safe crossing opportunities specifically designed for e.g. amphibians, reptiles, semi-arboreal species, and small mammals (soil and air humidity, cover, woody vegetation that spans across or under the road or canopy connectors such as ropes or other material).

While Table 17 classifies crossing structures based on their dimensions, there is no generally agreed upon definition of different types of crossing structures. One may also choose to modify the dimensions of an underpass based on the species of interest and the physical environment at the location of the underpass.

Table 17. Dimensions of the safe crossing opportunities recommended for implementation on or along the roads in the study area.

Safe Crossing Opportunity	Dimensions (as seen by the animals)		Safe Crossing Opportunity	Dimensions (as seen by the animals as they approach the crossing structure)
Wildlife overpass	50 m wide		Medium mammal underpasses	0.8-3 m wide, 0.5-2.5 m high
Open span bridge	12 m wide, ≥5 m high		Small-medium mammal pipes	0.3-0.6 m in diameter
Arboreal bridge	Rope bridge connecting canopy on both sides road		Animal Detection system	n/a
Large mammal underpass	7-8 m wide, 4-5 m high			

Table 18 provides an overview of the suitability of the seven different types of safe crossing opportunities for the medium and large mammal species that are known to occur in the area or that have been mentioned by various sources in Chapter 4. When evaluating the suitability, the authors assumed no human co-use of the crossing opportunities. The suitability of the different types of safe crossing opportunities is not only influenced by the size of the species, but also by species specific behavior.

Most animal detection systems only detect large mammals and are therefore by definition not suitable for medium and small species. Because the suitability of the different safe crossing opportunities depends on the species, and large landscape connectors (e.g. tunneling or elevated road sections) are rare, providing a variety of different types of safe crossing opportunities generally provides habitat connectivity for more species than implementing only one type of crossing structure, even if that structure is relatively large.

For some species there is little or no information on what type and dimension of crossing structure is considered suitable. However, for some species the researchers can make an educated guess. For example, ringtails are known to climb trees, nest in tree cavities, suggesting that arboreal bridges are a suitable type of crossing structure for this species.

Table 18. Suitability of different types of mitigation measures for selected species. ● Recommended/Optimum solution; ⭘ Possible if adapted to species' specific needs; ⊗ Not recommended; ? Unknown, more data required; — Not applicable (Clevenger & Huijser, 2011; O'Brien et al., 2013; Huijser et al., preliminary data; Clevenger, unpublished data).

	Wildlife overpass	Arboreal crossing	Open span bridge	Large mammal underpass	Medium mammal underpass	Small-medium mammal underpass	Animal detection system
Mammals							
Squirrels	●	●	●	●	⊗	⊗	⊗
Porcupine	●	⊗	●	●	?	⊗	⊗
Beaver	⭘	⊗	●	●	?	?	⊗
Opossum	●	●	●	●	●	●	⊗
Raccoon	●	⊗	●	●	●	?	⊗
Ringtail	●	●	●	●	⭘	⭘	⊗
Skunks	●	⊗	●	●	●	?	⊗
Fisher	●	●	●	⭘	⭘	⭘	⊗
Wolverine	●	⊗	?	?	?	⊗	⊗
Badger	●	⊗	●	●	●	●	⊗
Bobcat	●	⊗	●	●	●	●	⊗
Mountain lion	●	⊗	●	●	⊗	⊗	⭘
Kit fox	●	⊗	●	⭘	⭘	⭘	⊗
Grey fox	●	⊗	●	●	●	●	⊗
Red fox	●	⊗	●	●	●	●	⊗

Coyote	●	⊗	●	●	●	●	⊗
Deer spp.	●	⊗	●	●	⊗	⊗	●
Bighorn sheep	●	⊗	●	◉	⊗	⊗	●
Black bear	●	⊗	●	●	⊗	⊗	●
Amphibians	◉	⊗	◉	◉	◉	◉	⊗
Reptiles	◉	⊗	◉	◉	◉	◉	⊗

7.4. Spacing of Safe Crossing Opportunities for Wildlife

When wildlife fencing is installed alongside a road, the barrier effect of the road corridor is increased. Depending on the species concerned, a wildlife fence may be an absolute or a nearly complete barrier. Such barriers in the landscape are to be avoided as they isolate animal populations, and smaller and more isolated populations have reduced population survival probability. Therefore, when a wildlife fence is installed, safe crossing opportunities for wildlife should be provided for as well. This section discusses the distance between safe crossing opportunities.

The spacing of safe crossing opportunities for wildlife can be calculated in more than one way and is dependent on the goals one may have. Examples of possible goals are:

- Provide permeability under or over the road for ecosystem processes, including but not restricted to animal movements. Ecosystem processes include not only biological processes, but also physical processes (e.g. water flow).
- Allowing a wide variety of species to change their spatial distribution drastically, for example in response to climate change.
- Maintaining or improving the population viability of selected species based on their current spatial distribution. This includes striving for larger populations with a certain degree of connectivity between populations (including allowing for successful dispersal movements).
- Providing the opportunity for individuals (and populations) to continue seasonal migration movements (e.g. mule deer).
- Allowing individuals, regardless of the species, that have their home ranges on both sides of the highway to continue to use these areas. This may result in a road corridor that is permeable for wildlife, at least to a certain degree, and at least for the individuals that live close to the road.

A further complication is that individuals that disperse, that display seasonal migration, or that live in the immediate vicinity of a road may display differences in behavior with regard to where and how they move through the landscape, how they respond to roads, traffic, and associated barriers (e.g. wildlife fencing), and their willingness to use safe crossing opportunities. For example, dispersing individuals may grow up far away from the areas where one is used to seeing them, they may not move through habitat that we may expect them to be in, they typically travel long distances, much further and quicker compared to resident individuals, but successful dispersers may also stay away from roads and traffic, and other types of human disturbance that they are unfamiliar with. Safe crossing opportunities may not be encountered by dispersing individuals as they are new in the area and are not familiar with their location, and when confronted with a road or associated wildlife fence they may return or change the direction of their movement before they encounter and use a safe crossing opportunity. Furthermore, if dispersing individuals do encounter a safe crossing opportunity, they may be more hesitant to use them compared to resident individuals that not only know about their location, but that also have had time to learn that it is safe to use them. Since dispersal can be a relatively rare phenomenon, one may not be able to afford a dispersing individual to fail. Therefore, despite the fact that dispersers travel much further than resident individuals, designing safe crossing opportunities for dispersers does not automatically mean that one can allow for a greater distance between safe crossing opportunities.

Full scale population viability analyses can be very helpful to compare the effectiveness of different configurations of safe crossing opportunities. For this report the authors choose a simpler approach. Mule deer may have an average home range of about 450 hectares (ha) (diameter circular home range = 2,394 m) (443 ha in summer, 500 ha in winter (Kie et al., 2002). The distance between safe crossing opportunities for mule deer was set to be equal to the diameter of the home range, say about 2,400 m (Figure 44). This allows individuals that have the center of their home range on the road to have access to at least one safe crossing opportunity. However, individuals that may have had their home range on both sides of the road do not necessarily have access to a safe crossing opportunity (Figure 45). Finally, this approach assumed homogenous habitat and distribution of the individuals and circular home ranges, while in reality habitat and habitat quality may vary greatly, causing variations in density of individuals and irregular shapes home ranges. The authors of this report would like to emphasize that this approach does not necessarily result in viable populations for mule deer, and that not every individual that approaches the road and associated wildlife fence, will encounter and use a safe crossing opportunity. Nonetheless, it provides some guidance for how frequently a crossing structure suitable for mule deer may be desirable should fence length be longer than 2,400 m or so. Crossing structures that are suitable for mule can also be suitable or made to be suitable for many other species, e.g. when combined with a stream crossing and/or cover (e.g. rows of root wads for cover for small mammals, amphibians, and reptiles). Smaller species may also still be able to cross as the meshes of a standard fence for large ungulates are typically wide enough for small mammals, amphibians and snakes to pass through. If road mortality is to be reduced for smaller species too, smaller mesh fencing of smooth plastic sheets should be attached to the large mammal fence. Because the home range for these species and other species for which the fence is a barrier may be much smaller than for mule deer (see e.g. Huijser & Begley, 2012), additional crossing opportunities (in addition to the safe crossing opportunities for mule deer) may have to be provided for then. These crossing opportunities can typically be much smaller though, for species smaller than deer. The approach described above is not necessarily the only approach or the approach that addresses the barrier effect of the road corridor and associated fencing sufficiently for all species concerned. However, the authors do think that this approach would at least be consistent, practical, based on the available ecological data, and likely to result in considerable permeability of the road corridor and associated wildlife fencing for mule deer.

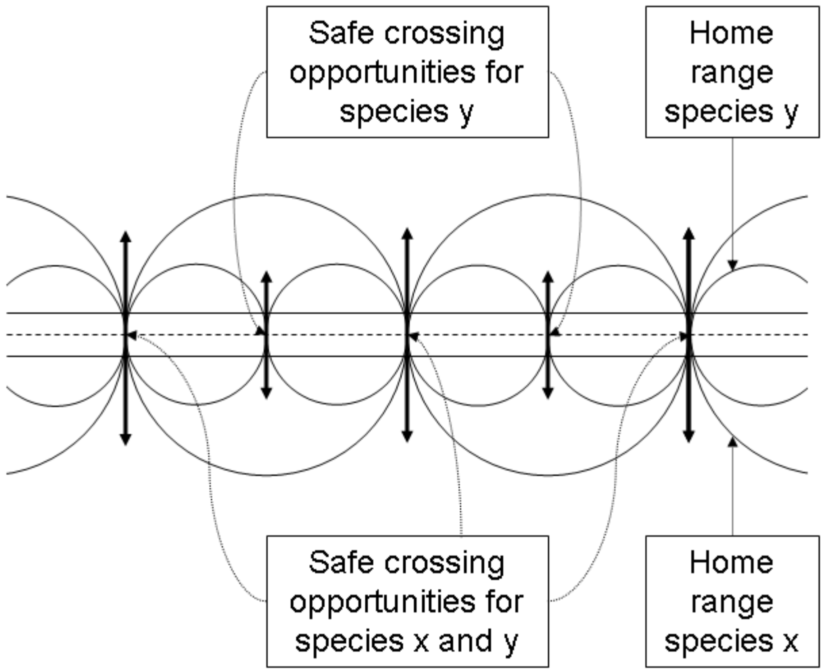

Figure 44. Schematic representation of home ranges for two theoretical species projected on a road and the distance between safe crossing opportunities (distance is equal to the diameter of their home range).

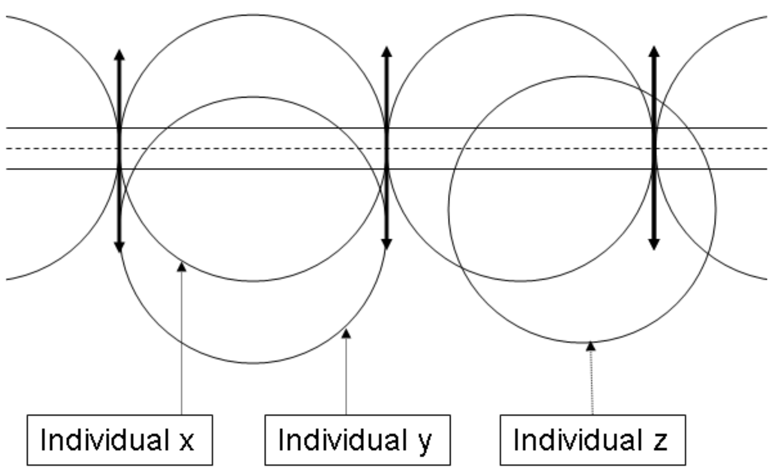

Figure 45. Schematic representation of home range for an individual (x) that has the center of its home range on the center of the road (access to two safe crossing opportunities), an individual (y) that has the center of its home range slightly off the center of the road exactly in between two safe crossing opportunities (no access to safe crossing opportunities), and an individual (z) that has the center of its home range slightly off the center of the road but not exactly in between two safe crossing opportunities (access to one safe crossing opportunity).

Another way to decide on "appropriate distance" between safe crossing opportunities is to evaluate what the spacing is for wildlife crossing structures on other wildlife highway mitigation projects. The average spacing for large mammal crossing structures in Montana (US Hwy 93 North and South), I-75 in Florida, SR 260 in Arizona, Banff National Park in Canada, and ongoing reconstruction on I-90 in Washington State is 1.9 km (range for the average spacing of structures in these individual areas is 0.8-2.9 km). However, the 1.9 km spacing is simply what people have done elsewhere, and it is not necessarily based on what may be needed ecologically, and the requirements for the target species in one area may be different from what is needed in another area.

7.5. Opinions of Caltrans Maintenance Personnel and Forest Service Personnel

Based on interviews conducted with Caltrans maintenance personnel and Forest Service personnel the researchers have heard the following opinions:

- Some local people may feel mule deer road mortality is not a problem or a minor problem that mostly affects non-locals, despite what the crash and carcass data may show. Therefore there may be no or little support for mitigation measures aimed at reducing mule deer-vehicle collisions.
- There may be little or no support for large mammal fencing in association with large mammal underpasses or other safe crossing opportunities for large mammals:
    - Private landowners may not want large mammal fencing adjacent to or in front of their property. This is especially important in the study area as all or nearly all of the hotspots are adjacent to privately owned land.
    - Upper portion Hwy 88, upper portion Hwy 4, and a section of Hwy 140 are officially designated as a State Scenic Highway (Caltrans, 2013b). Large mammal fencing may have a negative effect on landscape aesthetics.
    - Lower portion Hwy 88, lower portion of Hwy 4, Hwy 49, and Hwy 108, are eligible for designation as a State Scenic Highway (Caltrans, 2013b). Large mammal fencing may have a negative effect on landscape aesthetics.
    - At higher elevation there is open range for livestock. Large mammal fencing may affect grazing unit boundaries (though they would also likely reduce livestock-vehicle collisions).

  There may be more support for a lower large mammal fence (lower than 8 ft (2.4 m). Note that for white-tailed deer a 7 ft (2.1) m tall woven wire fence with an outrigger was found to be just as effective as a 8 ft (2.4 m) tall fence (Osborn et al., 2010). However, opaque woven landscape fabric attached to woven wire mesh fencing did not increase the barrier effect.
- There seems to be support for brush cutting in right-of-way to increase sight distance for drivers, which may lead to fewer deer-vehicle collisions. Though there is not much information on the effect of brush cutting on ungulate-vehicle collisions, some studies have reported 20-56% reduction for moose (Jaren et al., 1991; Lavsund & Sandegren, 1991). The timing of cutting shrubs can be important though as new growth can also attract certain ungulates (Rea 2003; Rea et al., 2010). Clearing the right-of-way from

shrubs, and potentially also trees is also believed to have the following additional advantages:
  - Increase opportunities for drivers and other people traveling the roads to see the landscape and surrounding mountains (considered scenic) (though cutting shrubs and trees may also be considered as a negative effect on landscape aesthetics)
  - A more open right-of-way may also serve as a fire barrier.
  - At higher elevation a more open right-of-way may also bring more sunlight on the road surface in the winter which may reduce ice on the road.
- There seems to be support for exit openings for wildlife in snow banks at higher elevation. Snow banks along a road can form a substantial barrier to animals, even large ungulates. This may cause the animals to try and outrun traffic rather than move off to the road (Garrett & Conway, 1999). The researchers were unable to find estimates on the potential effectiveness of creating exit openings in snow banks.

7.6. Recommendations for Crash and Carcass Hotspots Caltrans District 10

Most of the road sections with crash and carcass hotspots are relatively narrow, winding, and have a relatively narrow shoulder. Therefore, the researchers do not recommend animal detection systems. In addition, animal detection system projects should still be approached as a research project rather than the implementation of a tried and proven mitigation strategy with a predictable result, which may be the preferred option for the crash and carcass hotspots in Caltrans District 10. It does not appear that there are species for which wildlife overpasses are highly recommended and for which overspan bridges or large mammal underpasses would be insufficient. Therefore the researchers recommend large mammal overpasses as the primary wildlife crossing structures in and around the crash and carcass hotspots. If larger structures can be built (e.g. overspan bridges), wildlife use is likely higher than with large mammal underpasses.

Underpasses can be combined with stream crossings (preferably bottomless structures). Allowing for the natural streambed and banks to continue under the road is important to aquatic and semi-aquatic species. For terrestrial animals, including mule deer, a minimum path width of 2-3 m is recommended (Clevenger & Huijser, 2011).

Underpasses should be as open as possible; i.e span the underpass without supporting pillars or support walls if possible. If support is required, pillars are preferred over walls as pillars leave greater view distances for wildlife that approach the structure. The approaches to an underpass should be as gradual as possible so that the animals can see through the structure when they approach.

The researchers recommend placing large boulders or tree trunks or root wads inside and adjacent to underpasses. This provides cover for smaller species groups including small mammals, reptiles and amphibians.

The researchers recommend large mammal wildlife fencing in association with underpasses. This is likely to result in higher use of the crossing structures by large mammals and much reduce at grade crossing opportunities for the road length that is fenced. The longer the road section that is fenced, the less likely it is that animals that could or would use the underpass will walk to the fence end to cross at grade. While longer section of fencing are likely beneficial with regard to both human safety and the number of wildlife that cross the highway, there are several factors that may limit the presence and length of the wildlife fencing:

- Width of the right-of-way and the clear zones
- Access roads, including driveways (though gaps in the fence can be mitigated with wildlife guards or electric mats).
- Concerns about landscape aesthetics (landowners, drivers)

Unless direct road mortality is known to be a problem for amphibians and reptiles at a deer crash or deer carcass hotspot, the researchers do not recommend installing plastic sheets at the bottom at the large mammal fence.

Should continuous large mammal fencing be implemented, the researchers suggest placing large mammal underpasses at least every 2,400 m. The researchers also suggest evaluating if additional safe crossing opportunities for other species may be needed in between large mammal underpasses.

Since hotspots typically vary with regard to the specific road and right-of-way configuration, surrounding landscape, and land ownership, local conditions can have a strong influence what the opportunities for mitigation are at each hotspot.

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