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Modeling black bear-vehicle collision zones in Yosemite National Park

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MODELING BLACK BEAR-VEHICLE COLLISION ZONES IN YOSEMITE NATIONAL PARK

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ABSTRACT

MODELING BLACK BEAR-VEHICLE COLLISION ZONES IN YOSEMITE NATIONAL PARK

by Katie Elaine Rodriguez

The purpose of this study was to identify road and habitat characteristics associated with black bear-vehicle collisions in Yosemite National Park and to suggest proper mitigations to reduce their occurrence. Black bear-vehicle collision data collected by Yosemite National Park staff between 1995 and 2011 were used to identify variables associated with collisions. Geographic Information System (GIS) mapping software was used to map and split Yosemite roads into 1 km segments. After measuring road and bear habitat-related variables along each road segment, logistic regression analyses showed that segments with collisions were associated with crossing sites, understory vegetation, curves, close proximity to meadows, and a flat outbound shoulder slope. GIS spatial pattern and hot spot analysis were then used to group segments by their relative frequency of collisions: zero, low, moderate, and high. Logistic regression analyses of those same road segments, now grouped by their collision frequency, showed that segments with high frequencies of collisions were associated with a lack of visibility, fewer crossing sites, high understory cover, steep shoulder slopes, and close proximity to human development and meadows. The findings of this study were used to suggest effective and appropriate mitigation strategies for reducing collisions between bears and vehicles.

ACKNOWLEDGEMENTS

I thank Dr. Shannon Bros-Seemann for her guidance and unending enthusiasm for this project. Her motivation and support were crucial to my success. I thank my advising committee, Dr. Jerry Smith, Dr. Rachel Mazur, and Dr. Richard Taketa for their support and helpful comments throughout this process. I thank Yosemite National Park and the Resource Management and Science Division for their cooperation and granting of permission to conduct research within the park. I thank Victoria Seher, Caitlin Lee-Roney, and Ryan Leahy from the Yosemite Bear Management Program for use of their valuable data, guidance, and support through this process. I thank Katie Ehler, Dave Patrick, Emily Shiell, Jonathan Lewis, Nalani Ludington, Robert Hildebrandt, Robert Lester, and Jordan Bristol for their assistance in the field. I thank Michael Brown for his support and continued motivation for me to succeed. Most importantly I would like to thank Larry and Susan Rodriguez for their continued support in pushing me to follow my passion. A portion of this study was funded by the Michael Lee Scholarship for the Conservation of Biodiversity.

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Introduction

Wildlife-vehicle collisions are an increasing issue in North America. They are a significant cause of injury and mortality to wildlife (Brody and Pelton 1989, Waller and Servheen 2005, Reynolds-Hogland & Mitchell, 2007, Ament et al. 2008, Baruch-Mordo et al. 2008, Bissonette and Adair 2008, McCown et al. 2009). There are also secondary effects, including changes in movement patterns (Bissonette and Adair 2008), altered population demographics (Ament et al. 2008), and long-term effects on population viability (Litvaitis and Tash 2008). Collisions with large mammals also cause human death and injury as well as millions of dollars in property damage. Conover et al. (1995) found that over 1 million deer have been involved in vehicle collisions each year resulting in 29,000 human injuries, 211 human fatalities, and an average of $1,577 in property damage per deer-vehicle collision. Understanding the underlying variables that affect wildlife-vehicle collisions can inform wildlife managers how to mitigate and reduce their occurrence.

Previous research in North America has shown that wildlife-vehicle collisions have generalizable spatial and temporal patterns. Bissonette and Adair (2008) found that wildlife-vehicle collisions occurred in clusters along roads near good habitat. Baruch-Mordo et al. (2008) reported similar findings for black bear (*Ursus americanus*)-vehicle collisions. Brody and Pelton (1989) found black bears were more likely to cross roads with moderate traffic volumes and moderate speed limits, therefore increasing the probability of collisions in those areas. Dussault et al. (2006) found most collisions to occur during peak daily activity for several species of wildlife including deer and moose. Gunson et al. (2011) reviewed models in 24 studies and reported that collisions were commonly associated with adjacent steep slopes and areas with low visibility.

To enable managers to design appropriate mitigations to reduce collisions, detailed information is needed both on collision locations and the variables most closely correlated with the collisions (Gunson et al. 2009; Neumann et al. 2012). For example, Van Manen et al. (2012) reported that wildlife managers in North Carolina used data on black bear crossing patterns and locations to successfully mitigate genetic and behavioral impacts of roads on the bear population through construction of crossing structures. By geo-referencing wildlife-collision data with habitat and road data, one can measure variables potentially associated with collisions. Spatial models (e.g. ArcMap™ Kernal Density analysis or Logistic Regression) can then be used to identify areas in which collisions are likely to occur (Case 1978, Litvaitis and Tash 2008).

Black bear-vehicle collisions are increasing across North America (Baruch-Mordo et al. 2008, McCown et al. 2009). These collisions have been documented in North Carolina (Brody and Pelton 1989, Beringer et al. 1990), Colorado (Baruch-Mordo et al. 2008), California, West Virginia, Maine, Michigan, Tennessee, Montana, Idaho (Ament et al. 2008), and Canada (Clevenger et al. 2001). In Florida, where the local sub-species of black bear (*Ursus americanus floridanus)* is threatened, one of the highest causes of mortality is a collision with a vehicle (McCown et al. 2009). Elsewhere, collisions have increased because populations of black bears are increasing and encroaching on human development (Beckmann and Berger 2003, Baruch-Mordo et al. 2008, Beckmann and Lackey 2008). In fact, despite the loss of forested habitat, 34% of black bear populations in western North America are increasing (Beston 2011). Human development in black bear habitat has also introduced human food and trash into the black bears' diet (Lewis et al. 2011). As a result, these bears become conditioned to human food and habituated to human presence, thus spending more time around humans and human developments (Beckmann and Berger 2003) and having a higher likelihood of being hit by a vehicle since they spend more time on and near roads (Beckmann and Lackey 2008).

Black bears are especially susceptible to vehicle collisions because they, like most large mammals, travel long distances and are more likely to cross roads near high-quality habitat (Baruch-Mordo et al. 2008). Black bears travel throughout their range to disperse, seek mates, and locate seasonal food sources (Graber and White 1983, Baruch-Mordo et al. 2008, Greenleaf et al. 2009, Lewis and Rachlow 2011). For example, in Yosemite National Park, seasonal food sources are found at a range of elevations throughout the park, and when bears travel the long distances between them, they often must cross dangerous sections of road (Mazur et al. 2013). In the Sierra Nevada mountains, bears emerge in spring from their winter dens (generally in forested areas), and travel to wet meadows to access grasses, forbes, and other vegetation (Graber and White 1983). In late summer and fall, bears again travel great distances as food sources shift to berries, pine nuts and acorns (Graber and White 1983, Mazur et al. 2013). These seasonal movements of black bears in Yosemite increase the likelihood bears will cross roads, and therefore, the likelihood of black bear-vehicle collisions.

Yosemite National Park is an ideal place to study the correlates and impacts of bear-vehicle collisions, and to use the results to design targeted mitigations. Data on black bear-vehicle collisions have been collected through the Bear Management Program since 1995; since that time there have been over 300 reported collisions, averaging 17 bear-vehicle collisions per year. Road and habitat variables can be easily measured through field data collection and the availability of GIS map layers from the National Park Service. Through analyses of these variables it can be determined whether they correlate with bear-vehicle collisions. In addition, because Yosemite has a highly-studied population, it may be possible to determine if bear-vehicle collisions are impacting the overall black bear population in Yosemite National Park.

The primary goals of this study were to map bear-vehicle collisions, identify road and habitat characteristics associated with black bear-vehicle collisions, and to use the results to suggest proper mitigations to reduce the occurrence of collisions within Yosemite National Park. In addition, the methodology developed in this study could be used in other wildlife management programs. The data acquired by the Bear Management Program (1995-2011) were used to identify spatial patterns in bear-vehicle collisions. Measurements of road and habitat related variables were collected in hot-spot areas to identify key variables associated with collisions. Because variables contributing to the occurrence of a collision might differ from variables contributing to a high frequency of collisions, both types of models were examined.

Study Area

This study was conducted in Yosemite National Park which encompasses approximately 3,080 km^2. The park is located on the western slope of the central Sierra Nevada mountain range in California. Elevation ranges from 600 to 4,000 m. The climate is Mediterranean, with cool, moist winters, and warm, dry summers (Stephenson 1988).

Paved park roads total 344 km and are 2 lanes wide. The major roads within the park are Tioga Road (Highway 120), Big Oak Flat Road (Highway 120 west), Northside and Southside Drive within Yosemite Valley, El Portal Road (Highway 140), Glacier Point Road, and the Wawona Road (Highway 41; Figure 1). Posted speed limits on these roads are 25-45 miles per hour.

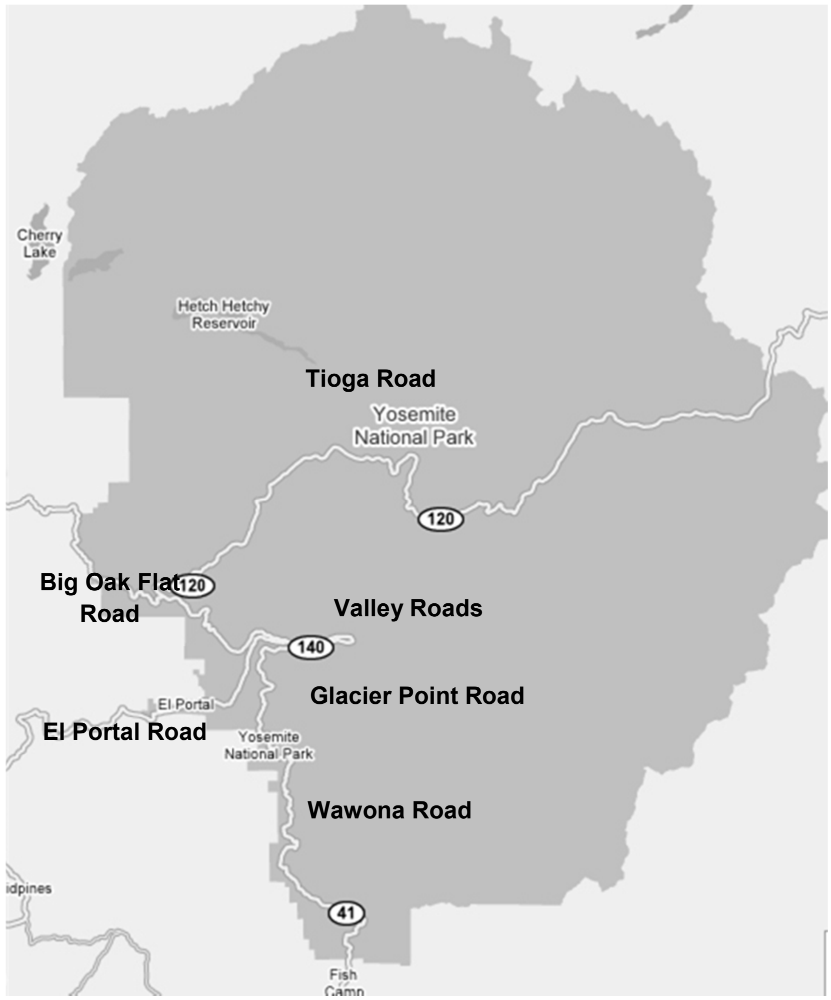

Figure 1. Map of major roads within Yosemite National Park. (Adapted from Yosemite NPS 2015).

Methods

Visitation rates and Geographic Information System (GIS) map layers of Yosemite's park boundary, park roads, streams and lakes, meadows, trails, trailheads, campsites, buildings and infrastructure, and aerial photos were obtained from the National Park Service (unpublished data, NPS 2011).

ArcMap™ was used to delineate 1 km road sections as a polygon feature layer for all the major roads within park boundaries.

Black bear-vehicle collision data for Yosemite National Park were collected by the Yosemite Bear Management Program between 1995 and 2011 (unpublished data, Bear Management Database 2011) and contained 280 reported and recorded collisions. The data consisted of reports of collisions from visitors and employees and, when possible, included date, day of the week, location, time, bear age class, bear gender, and final disposition of bear. However, 34 records were not included in subsequent analyses because they were located outside of park boundaries, the same incident was recorded more than once, or the description was too vague. All incidents with location information were used to construct a point-feature GIS map layer of bear-vehicle collisions from 1995-2011 in the ArcMap™ program. A frequency distribution of bear-vehicle collisions was constructed by counting all occurrences within each 1 km segment. Demographic patterns and temporal patterns for frequency of collisions for annual, monthly, day of week, and times of day were assessed graphically. To determine if visitation rates affected collision frequency, monthly mean visitation rates were compared to monthly mean frequency of vehicle collisions for 1995-2011 using a Pearson Product Moment Correlation (Zar 2010).

Two techniques were used to determine if there were high frequency collision locations (i.e. hot spots). The frequency distribution of collisions in 1 km road segments was compared to a Poisson distribution with a log-likelihood ratio test of goodness-of-fit (Zar 2010) to determine if collisions displayed clumped, uniform, or stochastic distributions. Clumped distribution would indicate presence of hot spots. Kernal Density analysis in ArcMap ™ was used to identify locations of hot spots. Kernal Density analysis highlights collision frequency with colors but extrapolates over the entire map layer surface. Road sections were classified into four categories: zero, low, moderate, or high collision frequency to determine which road and habitat variables were associated with collision frequency. Low frequency was considered 1 collision per 1 km road segment, moderate frequency was 2 to 3 collisions per road segment, and high frequency was 4 or more collisions per road segment from 1995-2011. Thirty-one specific road segments were then randomly selected for analysis of road and habitat characteristics (Table 1).

Table 1. One-km road segments surveyed per major road within Yosemite National Park with varying collision frequencies.

Surveyed Rd. Segments	Tioga	Big Oak Flat	El Portal	Wawona	Valley	Glacier Point	Total
High Frequency (4+)	4	2	0	4	3	2	15
Moderate Frequency (2-3)	3	0	4	0	0	0	7
Low Frequency (1)	1	1	0	0	0	0	2
Zero	1	1	0	3	1	1	7

Driving surveys were conducted in the field for the 31 km segments to measure road and habitat characteristics with a finer scale than was available through GIS map layers. Neon colored flagging was placed at each end-of-the-road segment to identify start and end points while conducting driving surveys. Each segment was driven two times in each direction for better accuracy of each measured variable. Each direction was labeled as “inbound” or “outbound” to capture the unique measures for each side of the road segment. Time elapsed, measured by a stop watch, at the posted speed was used to measure the proportion of roadway for three characteristics. Two characteristics reflected reduction in visibility for bears and drivers in areas in which bears do not have time to react to oncoming vehicles (i.e. small road margins ≤ 2 m across); steep roadside slope (> approximately 15^0) and understory vegetation greater than or equal to 2 m in height (which blocks vision for both bears and drivers). The third characteristic reflected possible bear crossing areas; using a stopwatch, time elapsed was recorded for the proportion of the road segment with possible crossing areas for bears. Possible crossing areas were defined as areas where topography allowed bears to physically cross roads. In addition, total numbers of drainages perpendicular to the road segment were counted to reflect potential crossing areas for bears.

The technique used in conjunction with the driving survey to assess whether drivers could react in time to avoid collisions, rated whether drivers are able to see a sufficient length of road that is within stopping distance of the vehicle at a posted speed, enabling the driver to stop in time to avoid a collision. Minimum physical stopping distance was calculated for posted speed limits in the park (Table 2) using a formula obtained from the Pennsylvania University School of Engineering and Applied Science (2015);

$$d = \frac{v_0^2}{2\mu g}$$ where v = initial velocity (m/s), = coefficient of friction (0.75) and g = gravity (9.81 m/s2)

Minimum stopping distance = physical stopping distance + reaction distance + braking distance where reaction distance = initial velocity (m/s) * reaction time constant (1.5 seconds) and braking distance = braking time constant (0.3 sec) * initial velocity (m/s).

For each speed limit, line of sight markers were installed in the research vehicle to visually indicate minimum stopping distance (Figure 2). A stopwatch was used to measure the time in which the visible road stretch was shorter than the minimum stopping.

Table 2. Minimum stopping distances (m) for posted speed limits (miles per hour) within Yosemite National Park.

Speed limit (mph)	Minimum Stopping Distance (m)
25	28
35	43
40	52
45	62

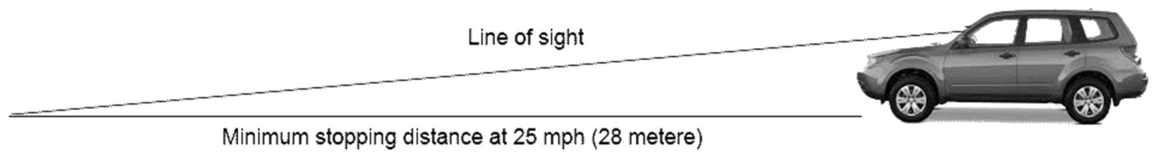

Figure 2. Method for identifying minimum stopping distance length for driving surveys.

GIS map layers were used to determine measurements for road and habitat related variables on a larger scale. The distance from road segments to human development (trailheads, trails, campgrounds, buildings) was used as an indicator of proximity to humans. Distance from road segments to meadows was measured as an indicator of distance to food and water source. Road straightness was defined as a ratio of straight line distance (1 km) to actual road length (km).

To determine which variables were significant in predicting whether a bear was hit or not, data were split into two groups: vehicle collisions presence or absence. All time-elapsed data were converted to distances and subsequently into proportions of road segment. A predictive model of whether or not a collision would occur was created with logistic regression analysis (SPSS™ version 22.0). The dependent variable was whether or not a collision occurred. Proportions of possible crossing areas, time while visibility was less than the stopping distance, understory vegetation, and roadways with downhill slope were included in the model as predictive variables. Additional predictor variables included in the model included number of drainages, speed limit, road straightness index, distance to human development, distance to meadows, and distance to trails.

Variables significant in predicting high frequency of collisions were examined by splitting locations in which a collision occurred into 2 groups based on natural breaks in the data: low frequency of collisions (1-4 collisions per1 km road segment) and high frequency of collisions (≥5 collisions per 1 km road segment). Logistic regression was conducted to create a predictive model of variables affecting frequency of collision (low and high). The same predictor variables for the preceding analysis were used for this analysis.

Results

In this study, there were distinct temporal patterns to bear-vehicle collisions that coincided with the level of visitation over the period from 1995 to 2011. The monthly mean number of bear-vehicle collisions and mean number of visitors were highly correlated ($r=0.930$, $p<0.001$) with the peaks for both occurring during the months of June through September (Figure 3). In addition, since 2007 the frequency of collisions has generally increased (Figure 4). The largest number of collisions occurred between the hours of 15:00-16:00 and 18:00-22:00 (Figure 5). There was a relatively small difference in collisions among days, but the highest number of collisions was on Sunday and Monday (Figure 6).

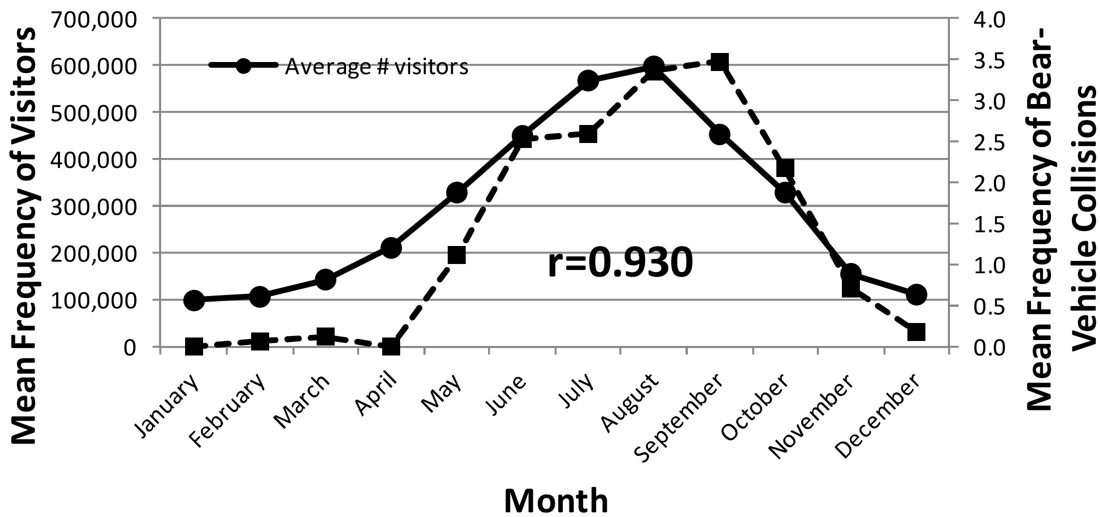

Figure 3. Monthly mean frequency of bear-vehicle collisions and monthly mean frequency of visitors in Yosemite National Park, 1995-2010. r is the Pearson Product Moment correlation between monthly mean frequency of bear-vehicle collisions and monthly mean frequency of visitors.

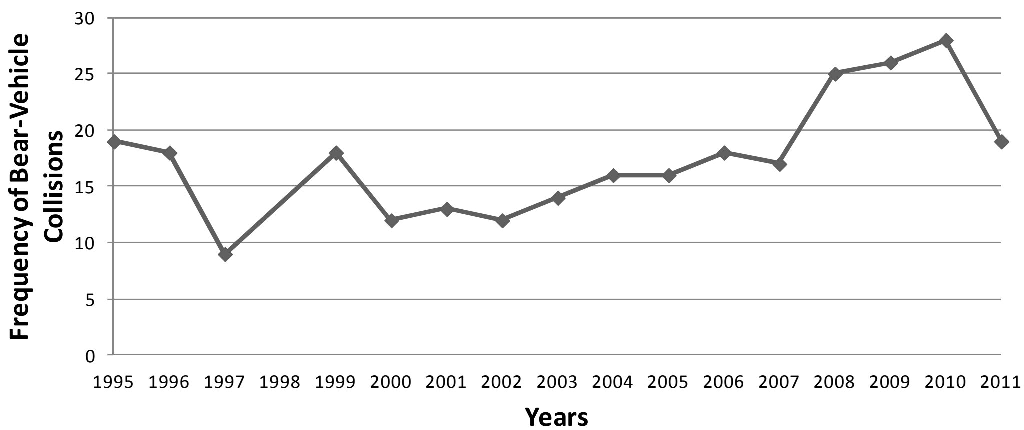

Figure 4. Yearly frequency of bear-vehicle collisions in Yosemite National Park, 1995-2011.

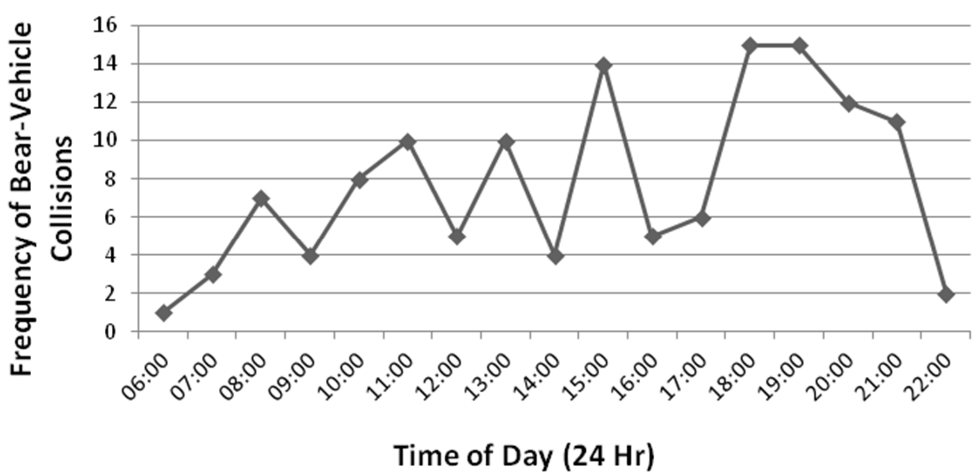

Figure 5. Frequency of bear-vehicle collisions in Yosemite National Park by hour of day, 1995-2011.

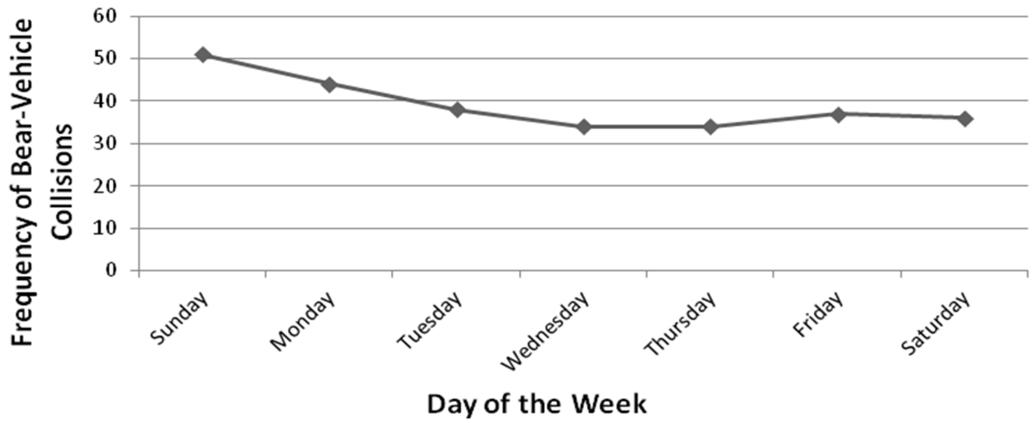

Figure 6. Frequency of bear-vehicle collisions by day of the week in Yosemite National Park, 1995-2011.

Qualitative analysis suggested differences in proportions of collisions within gender and age class. Bear gender information was available for only 22.1% of the total collisions (280), and for those data there were slightly more female bears (n= 35) involved in collisions than males (n= 27) (Figure 7). Seventy-three of the 280 bears involved in vehicle collisions were classified as adults, and cubs (n=52) were the second largest group of bears with age data, (Figure 8).

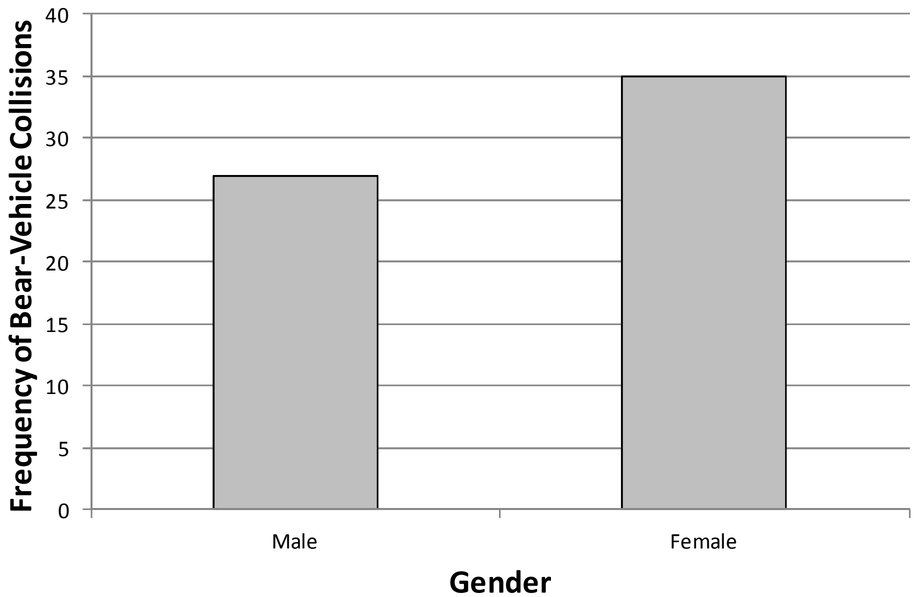

Figure 7. Frequency of male (n=27) and female (n=35) bears involved in collisions in Yosemite National Park, 1995-2011.

Figure 8. Frequency of bear-vehicle collisions by age class, adult (4+ years old), sub-adult (2-3 years old), yearling (1 year old), and cubs (<1 year old) in Yosemite National Park, 1995-2011.

Both the goodness of fit test and the ArcMap™ Kernal Density analyses showed the spatial pattern of bear-vehicle collisions was clumped. The goodness of fit test to a Poisson distribution (G= 39.251, p<0.001) was tested after construction of a frequency of collision per 1 km road segment was made and showed that the distribution was non-random, and the coefficient of dispersion (CD= 2.256), confirmed that the distribution was clumped (Figure 9). The ArcMap Kernal Density analysis also indicated a clumped distribution of collisions within Yosemite National Park (Figure 10). These clumped distributions are displayed as ArcGIS™ hot spots (areas with >4 collisions) along El Portal Road and Valley Roads (Figure 11), Wawona Road and Glacier Point Road (Figure 12), Big Oak Flat Road and Tioga Road west (Figure 13), and Tioga Road east (Figure 14).

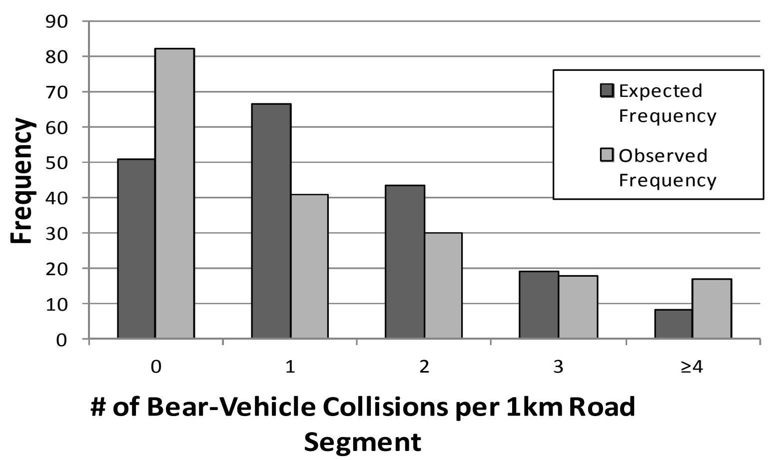

Figure 9. Results of goodness-of-fit test to Poisson distribution. Solid bars are expected by chance, grey bars are observed number of bear-vehicle collisions per 1 km road segment in Yosemite National Park, 1995-2011.

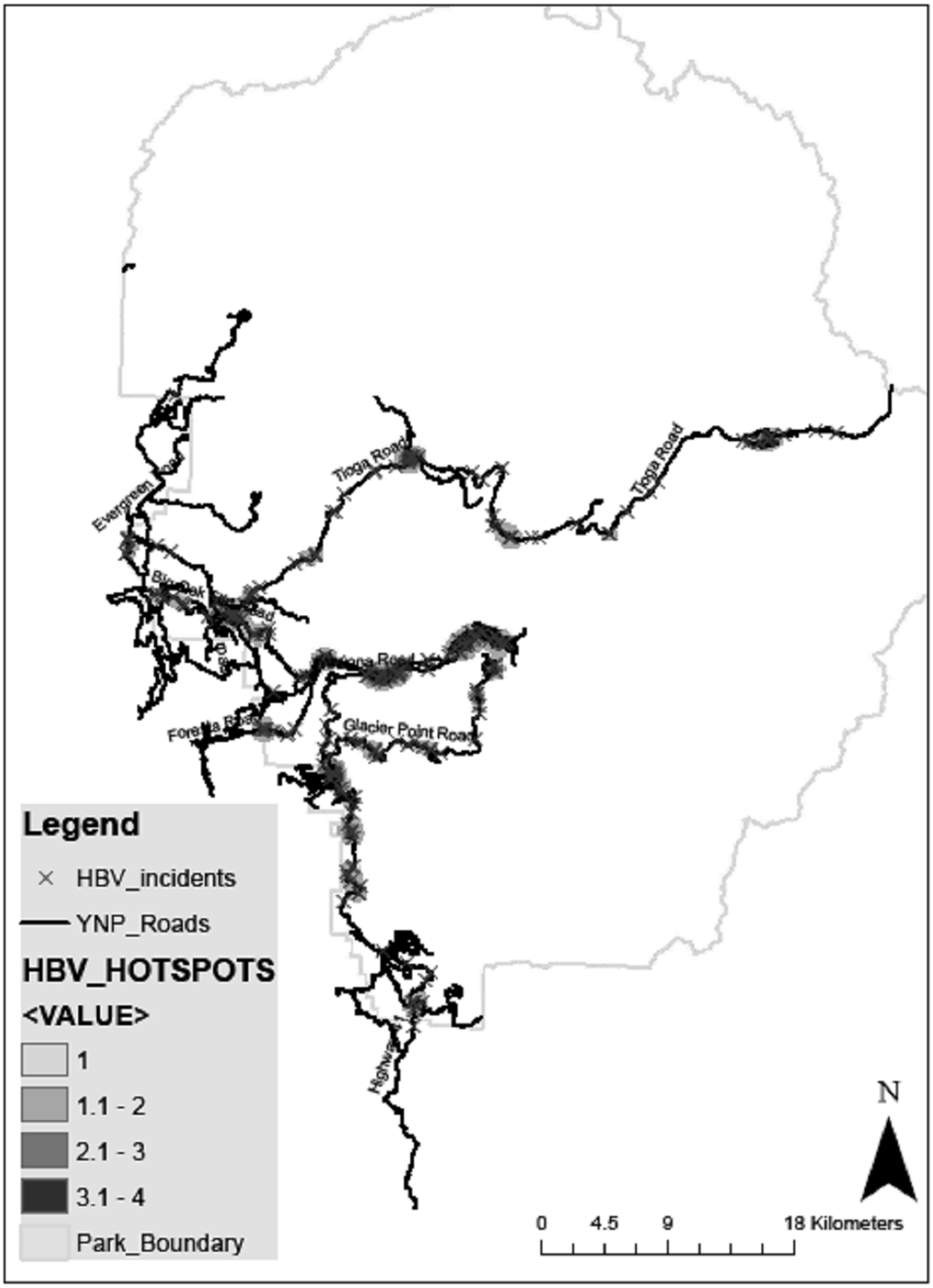

Figure 10. Kernal density hot spot map of bear-vehicle collisions in Yosemite National Park, 1995-2011.

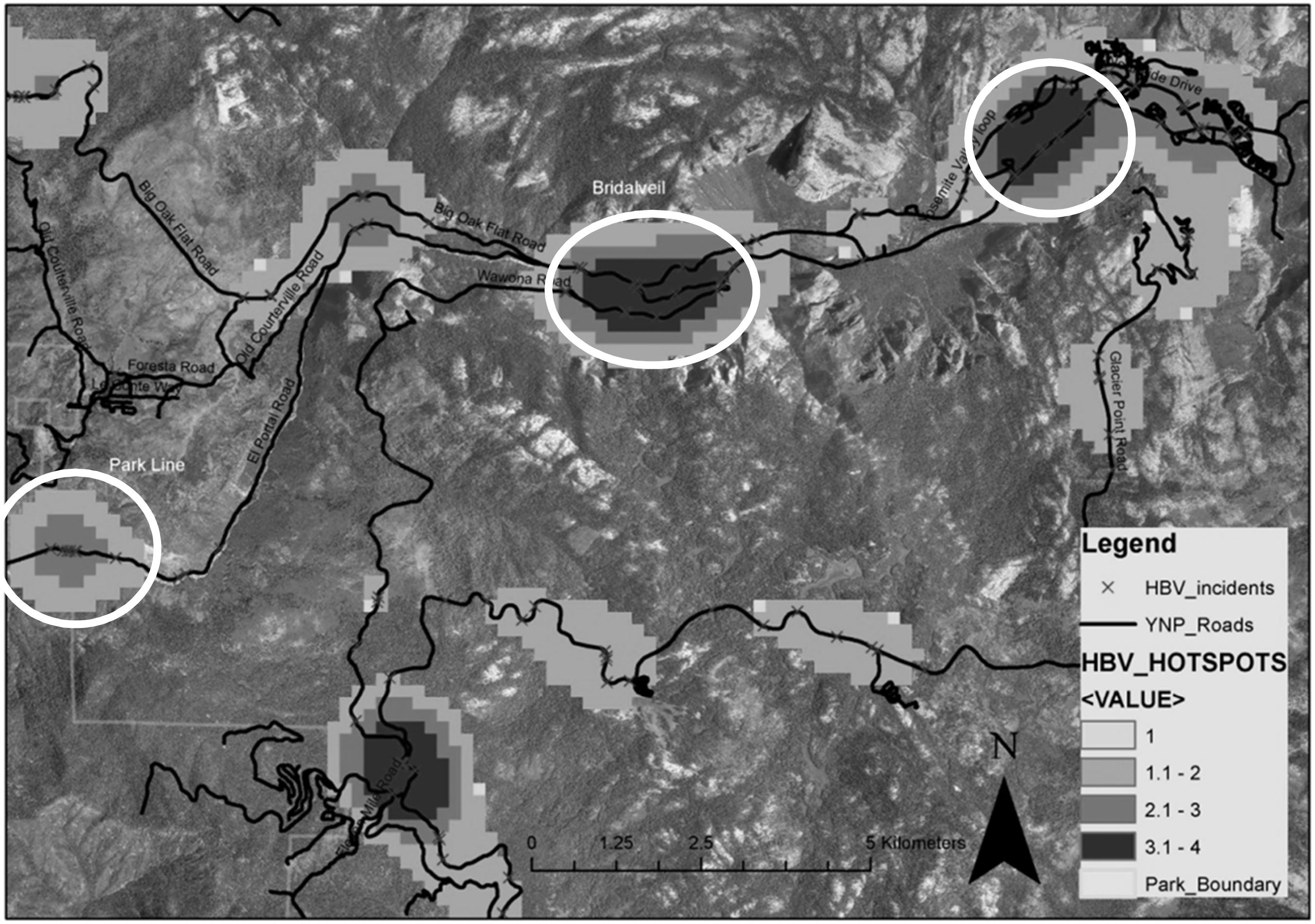

Figure 11. Kernal density hot spot map of bear-vehicle collisions of Yosemite Valley Roads and El Portal road (Highway 140) in Yosemite National Park, 1995-2011. Hot spot zones circled in white. (Adapted from Yosemite NPS 2015).

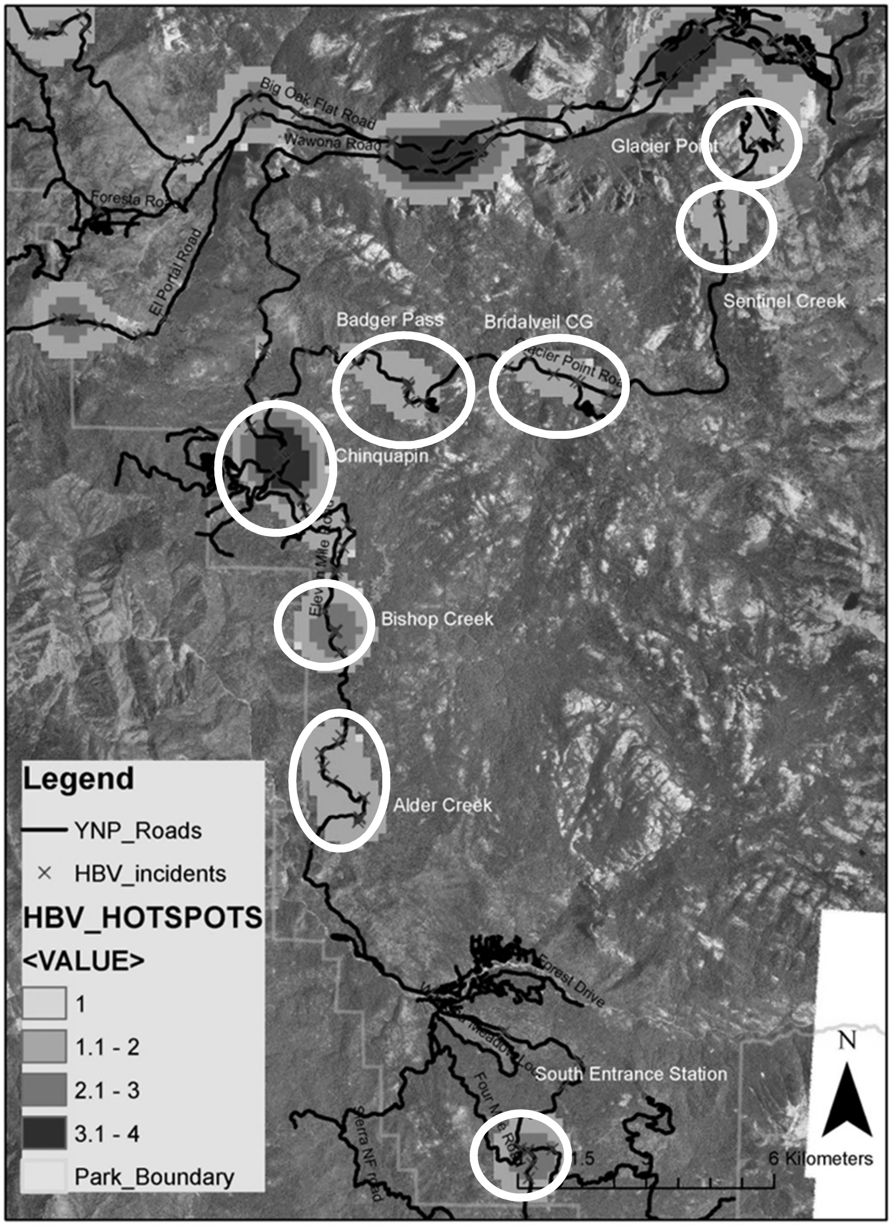

Figure 12. Kernal density hot spot map of bear-vehicle collisions of Glacier Point Road and Wawona Road (Highway 41) in Yosemite National Park, 1995-2011. Hot spots circled in white. (Adapted from Yosemite NPS 2015).

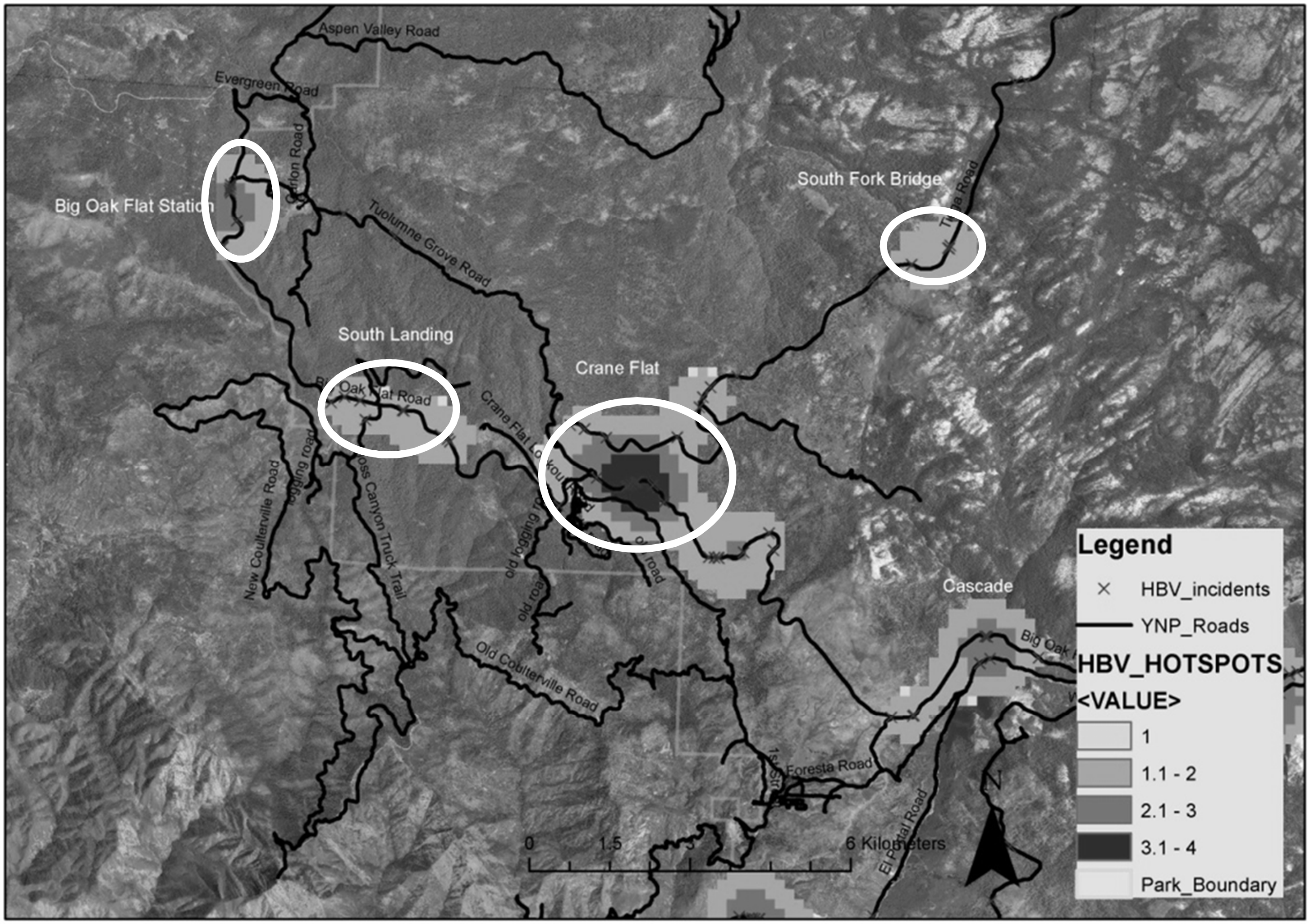

Figure 13. Kernal density hot spot map of bear-vehicle collisions of Big Oak Flat Road and Tioga Road West (Highway 120) in Yosemite National Park, 1995-2011. Hot spots circled in white. (Adapted from Yosemite NPS 2015).

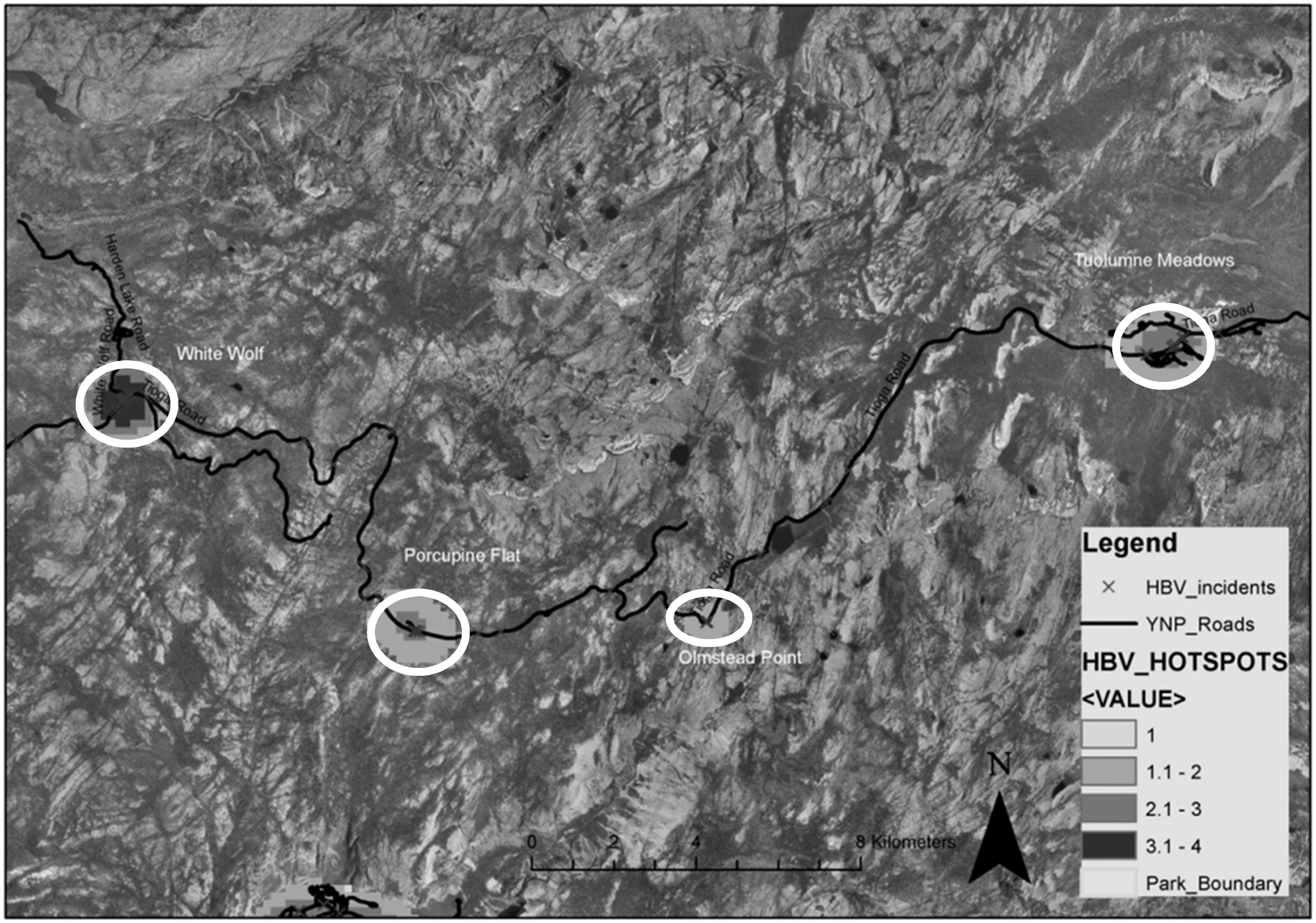

Figure 14. Kernal density hot spot map of bear-vehicle collisions of Tioga Road East (Highway 120) in Yosemite National Park, 1995-2011. Hot spots circled in white. (Adapted from Yosemite NPS 2015).

The logistic regression analysis showed that several habitat variables could be used to predict whether or not a bear-vehicle collision would occur (Table 3). After removing correlated variables, the following variables were used in the analysis: crossings, understory, road straightness, meadow distance, and outbound slope. The model was significant (p=0.005) and fit reasonably well to the data (Nagelkerke R^2 = 0.639). Although the predictive power was good, the model was much better at predicting the occurrence of a collision as opposed to an absence (Figure 15). Visibility, inbound shoulder, slope, drainages, and distance to trails were not important variables in predicting the presence or absence of a collision. The coefficients indicated that collisions were more likely when there were more crossing sites available, more understory vegetation, the road was not straight, closer proximity to meadows, and low outbound shoulder slope (Figure 16).

Table 3. Logistic regression analysis for the prediction of bear-vehicle collision presence/absence.

Variable	In the Final Model	P-value	Coefficient
Visibility	No	0.757	
Crossings	Yes	0.145	+0.040
Understory	Yes	0.165	+0.042
Inbound Shoulder Slope	No	0.757	
Drainages	No	0.396	
Road Straightness	Yes	0.014	-16.022
Distance to Human Development	No	0.511	
Distance to Meadows	Yes	0.225	-0.001
Distance to Trails	No	0.697	
Outbound Shoulder Slope	Yes	<0.001	-0.124
Constant			16.551

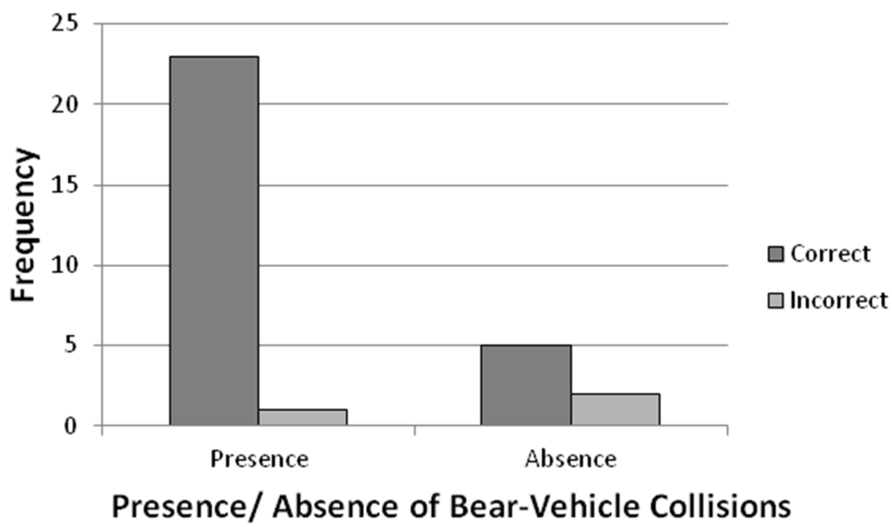

Figure 15. Predicting presence/absence of bear-vehicle collision frequencies.

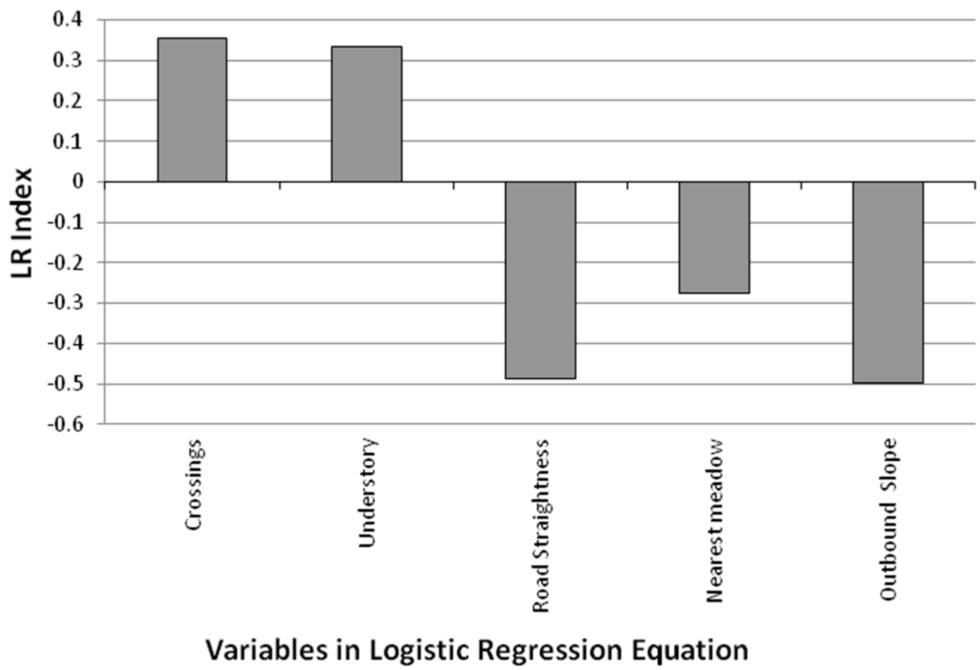

Figure 16. Logistic regression index values for variables in the bear-vehicle collision presence/absence logistic regression analysis. LR index= sign and the coefficient (1-p value-0.5).

For cases in which a bear-vehicle collision occurred, the logistic regression showed that several habitat variables could be used to predict where high frequency (≥5 collisions in a 1 km segment) collisions occurred (Table 4). After removing correlated variables, the following variables were used in the analysis: outbound slope, inbound slope, understory, lack of visibility, crossings, human development, and meadow distance. The model was significant (p =0.007) and fit well to the data (Nagelkerke R^2 = 0.758). Accuracy was greater for predictions of high frequency of collisions (Figure 17). Higher frequencies of collisions (≥5 per 1 km segment of road) were more likely to occur in areas where there was a lack of visibility, smaller areas to cross the road, high understory cover, high inbound shoulder slope, close proximity to human development and meadows, and high outbound shoulder slope (Figure 18).

Table 4. Logistic regression analysis of bear-vehicle collision for presence-only.

Variable	In the Final Model	P-value	Coefficient
Visibility	Yes	0.113	+0.107
Crossings	Yes	0.016	-0.341
Understory	Yes	0.253	+0.101
Inbound Shoulder Slope	Yes	0.069	-0.129
Drainages	No	0.505	
Road Straightness	No	0.818	
Distance to Human Development	Yes	0.002	-0.004
Distance to Meadows	Yes	0.026	-0.007
Distance to Trails	No	0.605	
Outbound Shoulder Slope	Yes	0.006	+0.150
Constant			28.383

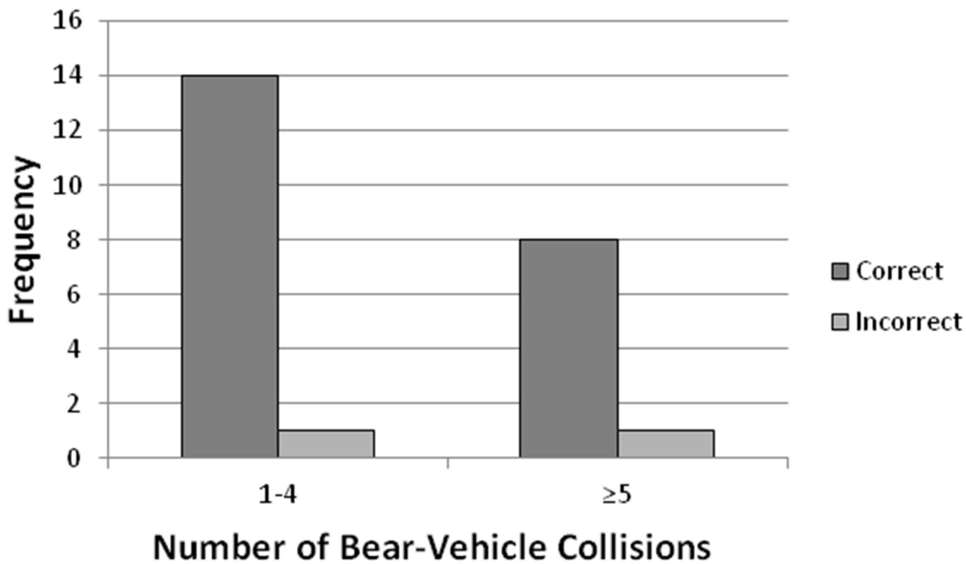

Figure 17. Predicting low (1-4) and high (>= 5) frequencies of bear-vehicle collisions.

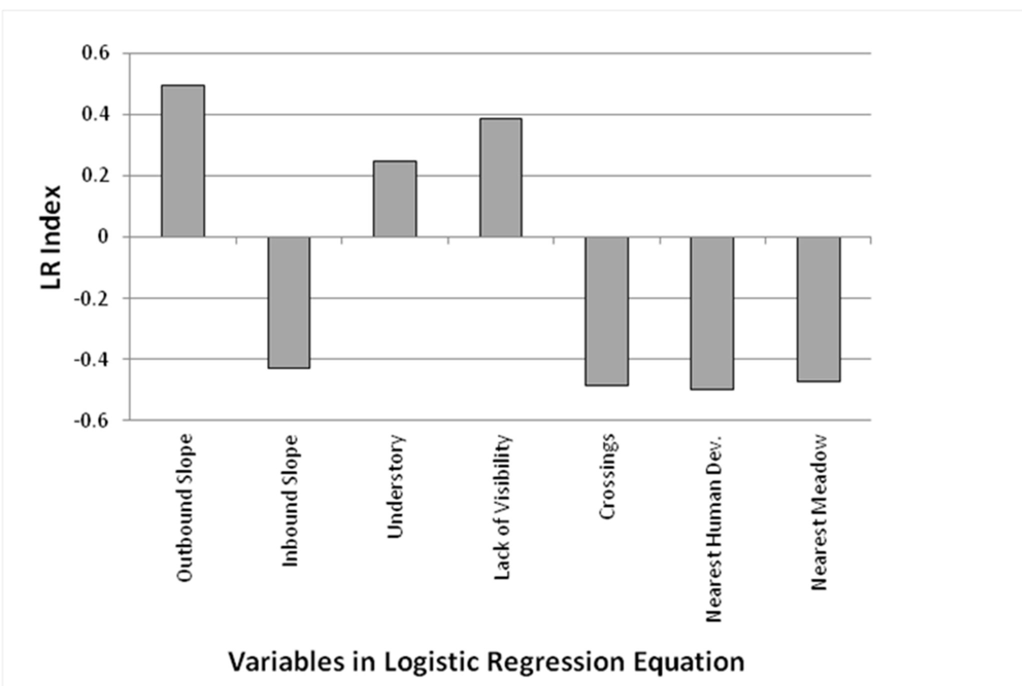

Figure 18. Logistic regression index values for variables in the bear-vehicle high frequency (>5) collision logistic regression analysis. LR index= sign and coefficient(1-p value-0.5).

Discussion

Black bear seasonal movement and daily activity patterns most likely played a major role in bear-vehicle collisions. The majority of vehicle collisions occurred between the months of June through September when bear movement and activity were at their highest levels. During early summer, black bears, particularly adult males, are more active because they are seeking mates (Lewis and Rachlow 2011). Bears are more active when seasonal food sources change from summer to fall (Graber and White 1983, Grenfell and Allan 1983, Greenleaf et al. 2009) which increases movements of bears of all age classes. Mazur et al. (2013) showed that bears increase movement to various parts of Sequoia National Park and changed elevation in response to seasonal food source changes. McCown et al. (2009) showed that, in fragmented habitats in Florida, black bears must cross roads to seek mates, dens, and seasonal food sources. Ament (2008) found that several National Parks had documented a relationship between wildlife-vehicle collisions and movement during migration or other movement events for several species.

Black bear daily activity patterns might also have affected collision frequency. Black bears naturally forage diurnally; however human food-conditioned bears tended to be more active nocturnally (Matthews et al. 2006). In this study, collisions were more frequent during dusk hours, coinciding both with activity patterns of food-conditioned bears that enter developed areas at night (Matthews et al. 2006), as well as with activity patterns of wild bears that are done foraging for the day and could be traveling to a resting spot for the night (Lewis and Rachlow 2011).

While there appeared to be slightly more females involved in collisions than males, there are two factors that limit confidence in this conclusion. First of all, gender can only be determined accurately in deceased bears, but not all bears died at the collision site and it is unknown if there is a bias in survivorship. Second, there may be gender bias in reporting; unless a bear has cubs, and is therefore female, gender is difficult to visually discern. Male sub-adult black bears (2-3 years old) disperse farther from their mother's home range than females (Lee and Vaughan 2003) between May and July (Lee and Vaughan 2004), which increases their likelihood of crossing roads during this time. This suggests that males would be more likely to be involved in collisions, but that was not clear in the data. A goal of future studies should be to determine if female mortality is actually greater because female bears drive population growth (Beston 2011).

This study suggested that cub mortality might be an important parameter affecting bear demographics. If one assumes that the collision proportions reflect actual population proportions, then the data suggest that 28% of the current population is made up of cubs; thus the proportion of cubs in the population has increased since Graber's assessment (1982; 20%). However, the current proportion of cubs is likely to be less than Graber's assessment (1982); Graber's study was conducted when black bears in Yosemite had ready access to high caloric human food (Greenleaf et al., 2009; Matthews et al., 2006), and females were more likely to have larger litter sizes. After installation of bear-proof food storage containers between 1974 and 1988, Keay (1995) found a reduction in Yosemite black bear's litter sizes while Greenleaf et al. (2009) and Hopkins et al. (2014) have shown that, as a result of the Bear Management program, human food sources have become a decreasing part of Yosemite black bears' diet. Therefore, females are likely to have fewer cubs than previously and cubs likely make up less than 20% of the population. Cub mortality attributable to vehicle collisions may then result in greater impacts as the population returns to more natural demographic proportions. Cub survival rates are generally not high for black bears in the western United States (Beston 2011) and the additive effects of vehicle collisions as a mortality source may exacerbate the problem. Having updated population demographic data should be a goal of future studies.

In this study, locations of bear-vehicle collisions in Yosemite National Park were shown to be clustered rather than random. Previous research has also found that wildlife-vehicle collision hot spots occur in clustered distributions (Clevenger et al. 2003, Bissonette and Adair 2008, Litvaitis and Tash 2008). A study conducted on black bear-human conflict in Colorado found that road kills were clustered (Baruch-Mordo 2008). This is common for other species such as moose (*Alces alces*) in Canada whose road kills exhibited both spatial and temporal patterns (Dussault et al. 2006). Gunson et al. (2011) reviewed several collision models and also found that wildlife-vehicle collisions were not randomly distributed, but were clustered.

In this study, results of the analyses for presence/absence of collisions and collision frequency appeared to give contradictory results with respect to road crossings. For the analysis of collision presence/absence, collisions were more likely to occur in areas with more opportunities to cross. However, the analysis for collision frequency indicated that higher frequency of collisions was associated with fewer opportunities to cross. This means that collisions were present in areas with high possible crossing percentages, but higher frequencies of collisions occurred when the possible crossing area was restricted. This could be explained by a funneling effect; when the crossing areas are reduced, the density of bears in the crossing area should be greater. If the crossing area is classified as hazardous, the collision frequency should be correspondingly greater. Litvaitis and Tash (2008) found that higher frequency of collisions with wildlife is associated with topography that created a funneling effect that directed movement of wildlife to a specific road segment. Funneling seemed to be a factor in places like White Wolf where topography creates a small segment of road that is crossable for bears; however in places like Tuolumne Meadows where the topography is flatter and contains more areas to cross, other variables may attribute to collisions.

This study has shown that road segments near meadows and/or human development are of special concern with respect to bear-vehicle collisions. In spring, when vehicle traffic is increased, Yosemite meadows become an important food source (Graber and White 1983, Grenfell and Brody 1983, Greenleaf et al. 2009), and bears are more likely to cross roads to access these sites. Because roads often bisect meadows complexes, bears may be more likely to cross roads in these areas to forage. Collision frequency was also greater near human development (i.e. campgrounds, trailheads, and picnic areas) which was also observed by Neumann et al. (2012) in Sweden. Bears attracted to human food could be more likely to be in these areas and thus crossing nearby roads. Like meadows, developed areas are generally near water sources and have flatter terrain which also makes them easier to traverse. Beckmann and Lackey (2008) found that urban-dwelling bears that occupied developed areas in the Lake Tahoe region of the Sierra Nevada were more likely to be hit by vehicles. In Yosemite National Park, the problem is exacerbated because human development and meadows are often in close proximity.

Driver behavior and road design played important roles in predicting occurrences of bear-vehicle collisions. Visitor activity level appears to be a key factor in the frequency of black bear-vehicle collisions; the greater the activity levels, the more collisions. While specific traffic volume data were not available for Yosemite National Park, it is safe to assume that the number of vehicles was increased when visitation was higher. Within peak tourist season, collisions tended to occur at higher levels later in the day, especially 18:00-22:00, at dusk, when glare and low lighting conditions from the setting sun would reduce visibility for drivers. Limited visibility when combined with a higher number of bears crossing the roads would make collisions more likely. The increased frequency of collisions between 15:00-16:00 is not well understood, but may be due to increased vehicle traffic during this hour from visitors ending daily activities and heading out of the park or back to campgrounds from trailheads. In addition, more collisions occurred on Sundays (and Mondays) when visitors were more likely to be exiting the park from a weekend trip.

Whether traffic volume is a factor in wildlife-vehicle collisions is debatable. Traffic volumes alone are insufficient to explain road impacts (Reynold-Hogland and Mitchell 2007), but bear avoid roads with high traffic volumes (Brody and Pelton 1989, Beringer et al. 1990, Clevenger et al. 2003, McCown et al. 2009). Therefore, when there is a continuous stream of traffic, it is likely that wildlife avoid roads. But where traffic is highly variable, it is more likely that wildlife will attempt to cross roads. Clearly, a successful mitigation effort would require a better understanding of collision frequency and traffic volume levels.

As with Gunson et al. (2011), this study showed road characteristics associated with visibility of both drivers and bears are related to collision frequency. Certain features reduce visibility. Wildlife-vehicle collisions are more likely to occur because of characteristics such as road alignment and road-side topography (Gunson et al. 2011). High levels of understory or steep slopes would block visibility, and both of these variables were associated with high frequency of collisions. In this study, in areas where bears had to climb up to cross the road, the collision frequency was higher. There was an apparent difference in results for the outbound slope characteristic between the presence/absence of collisions model versus the low/high frequency of collisions model. In the presence/absence model, the results indicated that slopes were flatter where collisions occurred. Whereas, in the low/high frequency model, within areas in which collisions occurred, steeper slopes lead to a higher frequency of collisions. This could mean that within areas where collisions occurred, areas with a steep slope were more “dangerous” and lead to higher frequency of collisions. In a 20 year study on black bear behavior in North Carolina, Reynolds-Hogland and Mitchell (2007) showed that bears commonly travel up and down steep slopes. Collision frequency was perhaps more likely in these areas because the time in which bears would have to react to an oncoming vehicle would be reduced. The current study also showed that poor visibility was associated with driver reaction time: collision frequency was greater when the visible length of roadway was less than the minimum stopping distance; drivers could not stop in time if a bear was in the roadway. Curvy roads were also associated with high frequency of collisions; blind corners also impair visibility for both bears and drivers. Curvy roads are more likely in the mosaic of habitats that provide good bear habitat and have higher bear use. These combined variables would cause some road sections to have higher likelihood of collision (hot spots).

There are several types of mitigations that can be implemented to change driver behavior and/or bear behavior to reduce collision occurrence. The least expensive driver-related mitigation is to construct warning and crossing signs (Glista et al. 2009). Signs can educate and warn drivers about black bear-vehicle collision issues in specific targeted areas. Ament et al. (2008) found that 53% of National Parks surveyed utilized signage, and signage was the most common form of mitigation. The effectiveness of signs could be enhanced by enforcing reduced speed limits within those areas (Glista et al. 2009); a reduced speed limit would allow drivers see within their minimum stopping distance and allow them to avoid collisions. Increased law enforcement patrolling could then dissuade drivers from violating posted speed limits. Yosemite National Park has implemented a "Red Bear Dead Bear" program incorporating temporary signs at collision sites (Freeman 2007) to educate drivers about their role in reducing bear-vehicle collisions, but the effectiveness of this program has not yet been evaluated.

Modifications to increase visibility or to increase time for bear reaction would also help to reduce collision frequency. Poor visibility due to roadside understory or blind curves could be remedied by removing vegetation (brushing) and vision impairments along roadsides. In hot-spot areas, increasing roadside margin widths could increase the time in which bears could react to oncoming vehicles. Roadsides with steep slopes have little or no margin and other margins are typically less than 2 m wide. Increases in road margins may also reduce mortality rates associated with collisions. The majority of bear carcasses found on road margins suffered massive head trauma. This finding suggests that bears were not aware of or could not react to oncoming vehicles.

To identify areas in which driver visibility was reduced, this study employed a driving survey as a novel method for rapid assessment of driver visibility limitations. These driving surveys were able to characterize a roadside slope, minimum stopping distance visibility, extent of understory cover along roadsides, presence of drainages, and possible crossing areas, but with less time and effort than with traditional ground survey techniques such as line transects or quadrats adjacent to roadways (Krebs 1999). This method also was more precise than using GIS mapping software since the surveyors could collect finer scale measurements and observe characteristics difficult to observe through GIS mapping.

Extensive road modifications in hot spot areas could provide an effective but expensive solution to reducing bear-vehicle collisions. For example, structures such as large culverts and overpasses have been shown to reduce collisions (Ament et al. 2008, Glista et al. 2009, Van Manen et al. 2012). These structures could be above or below the roadway and can be used in conjunction with directional fencing to lead bears and other wildlife into crossing structures. In Yosemite there are many existing drainage culverts located within or just outside of road kill hot spots, and a culvert-camera survey conducted along the Wawona Road (Highway 41) within Yosemite has shown that many species, including bears, have used drainage culverts to pass under the road (unpublished Yosemite National Park study). These structures could be improved by enlarging them to better facilitate large animal movement. In addition, new wildlife-specific structures could be created to allow bears to pass over the road.

Collision studies could also be useful to park managers in developing long term plans to reduce impacts of roads on wildlife populations. Wildlife-vehicle collision data could also be useful when planning new roads or development near wildlife habitat. Malo et al. (2004) stated that understanding important predictive variables can allow managers to implement mitigations in the road design planning phase instead of dealing with the issue after development is completed.

A successful program to reduce impacts of wildlife-vehicle collisions requires data collection and analysis to inform mitigation techniques. Collection of wildlife-vehicle collision data (GPS coordinates, species, date, etc.) is the first requirement to determining if hot spots exist. Transportation agency employees and drivers can participate in recording collision data, especially with the creation of online wildlife-vehicle collision databases like CROS (California Road Kill Observation System). Once data have been acquired, spatial analyses can help determine if hot spots exist and whether there are habitat or road-related variables related to collision occurrence. Additional data on population demographics (population size, age class and gender proportion) would be essential to determine how collisions actually affect wildlife populations. Wildlife movement patterns would be critical to assess importance of seasonal food sources for targeted species. Monitoring wildlife movement through drainage culverts within hot spot areas would also be useful in determining whether wildlife are using existing structures.

Wildlife-vehicle collisions will continue to occur unless steps are taken to reduce risk in dangerous sections of road. The process of investigation demonstrated in this study is an important first step in any mitigation as has been used in previous research. Land managers and transportation agencies have acknowledged the wildlife-vehicle collision issue and have developed plans to reduce collisions. (Ament et al. 2008, USDOT FHWA 2008). Many researchers (Clevenger et al. 2001, Bissonette and Adair 2008, Litvaitis and Tash 2008, Glista et al. 2009, Van Manen et al. 2012) have demonstrated the effectiveness of the measures proposed in the present study for reducing wildlife-vehicle collision.

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