SPATIAL, ROADWAY, AND BIOTIC FACTORS ASSOCIATED WITH BARN OWL (*TYTO ALBA*) MORTALITY AND CHARACTERISTICS OF MORTALITY HOTSPOTS ALONG INTERSTATES 84 AND 86 IN IDAHO

by

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DEDICATION

For Pik and Mags and the S.S. Seine.

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ABSTRACT

One of the world's highest roadway mortality rates for barn owls (*Tyto alba*) occurs along Interstate 84/86 (I-84/86) in southern Idaho. Although mortality occurs in numerous portions of the I-84/86 corridor, there are segments where relatively much higher numbers of owls are killed (in total comprising >20% of the corridor total, hereafter "hotspots"). My objectives were to 1) identify areas of greatest mortality (hotspots), 2) understand the spatial, roadway, and biotic factors potentially contributing to barn owl-vehicle collisions, and 3) assess how mortality hotspots have changed over time. If factors contributing to barn owl mortality along highways can be identified, it may be possible to find ways to reduce barn owl-vehicle collisions in this region. To do so, I conducted road surveys to identify locations of barn owl-vehicle collisions, and quantified spatial, roadway, and biotic factors along the focal highway to examine how they related to patterns of barn owl roadway mortality. I also quantified mortality hotspots to examine temporal and spatial changes between a previous survey in 2004-2006 and this study in 2013-2015.

Standardized road kill surveys conducted by Than Boves from 2004 to 2006 located 812 dead barn owls. Between 2013 and 2015, I located another 550 dead barn owls. I characterized nine spatial, 19 roadway, and nine biotic variables that may potentially affect barn owl roadway mortality using squares of 1-, 3-, and 5-km lengths centered on 120 randomly selected sites along the I-84/86 corridor. I evaluated variables at each of the three scales in relation to the number of dead barn owls counted along 1-

and 5-km highway segments to determine their respective best scales (either 1-, 3-, or 5-km) using Akaike Information Criterion (AIC_C). This approach produced two sets of models: the 1-km highway segment model set and the 5-km highway segment model set.

The final variable set included 14 variables for both the 1- and 5-km model sets. I assessed the potential effects of all possible combinations of these variables within each set (spatial, roadway, and biotic) on number of dead barn owls in 1- and 5-km highway segments using Generalized Linear Models within an AIC_C information theoretic model selection framework and combined the variables from the top models in each variable set into a final set in which I assessed all possible combinations (a total of eight variables for the 1-km set and seven variables for the 5-km set). I averaged the variables into a final model for the 1-km set, whereas model averaging was not necessary for the 5-km set. One of the variables in the final 1-km model (width of the median) was further analyzed to determine its potential correlation with percent land cover type.

In the final 1-km model set, percentage human structures, cumulative length of secondary roads (length of all roads other than I-84/86), and width of median had an inverse relationship with the number of dead barn owls/1-km segment/survey. Percent land cover type varied with the width of the median in that the median was generally wider when the highway was surrounded by shrubs ($r_s = 0.30$, $p = 0.0008$) and narrower when surrounded by crops ($r_s = -0.24$, $p = 0.009$). The number of dead barn owls/1-km segment/survey increased with commercial average annual daily traffic (CAADT), small mammal abundance index, and when the plant cover type in the roadside verge was grass. The final model for the 5-km model set included percentage of crops in which the number of dead barn owls/5-km segment/survey increased as the percentage of crops increased. Barn owls are associated with agricultural lands and thus less likely to occur in areas with high percentages of human structures, secondary roads, and when the median is wide in shrublands. Barn owl carcasses increased with higher small mammal abundance index values as well as when there was grass in the verges. Furthermore, the small mammal abundance index was greater in grass versus mixed shrub verges (Wilcoxon rank sum test: eastbound verge, W = 1507, p = 0.01; westbound verge, W = 2255, p <0.001) indicating barn owls may be attracted to grassy portions of the highway with higher levels of small mammals for hunting prey. Finally, commercial traffic may be more detrimental to barn owls because of the higher profile of commercial vehicles compared with passenger vehicles or perhaps the owls get caught in wind vortices created by semi-trailer trucks.

I evaluated temporal and spatial changes in hotspots between survey periods using point density estimation and KDE+. Additionally, of the 120 randomly selected sites, I calculated which fell within an area delineated as a hotspot and which did not as defined by the point density estimation analysis. I compared characteristics of the two types of sites (hotspot and non-hotspot) for the 14 spatial, roadway, and biotic variables selected for final modeling.

The area between Bliss and Hazelton was the section of I-84/86 with the highest rates of barn owl-vehicle collisions in both surveys, although particular hotspots did exhibit some expansions and contractions between 2004-2006 and 2013-2015. Two of the historical hotspots no longer appeared as hotspots in the recent surveys indicating they perhaps have shifted or were so fatal they reduced the local barn owl population and thus no longer appear as hotspots. Therefore, these historical hotspots may still be important mortality zones and important for future mitigation consideration as the hotspots potentially have reduced the barn owl population in these areas.

The most important difference between hotspots and other sites was the higher number of secondary roads (Wilcoxon rank sum test: $W = 613$, $p = 0.001$) and higher traffic volume ($W = 600$, $p = 0.002$) in hotspots. However, hotspots were also generally situated close to the Snake River Canyon and other water features which should have more prey, provide nesting and/or roosting sites, and attract owls; had low slopes (level terrain) which would allow owls to fly low to the pavement; narrow medians (correlated with cropland); and flexible rather than rigid pavement type (potentially related to noise level), and did not contain the highest number of dairies (which should attract owls to their higher rodent populations). The hotspots were also in regions of I-84/86 with moderate to high small mammal abundance and features that should correlate with higher rodent abundance: low percentages of human structures near the highway, grass cover types in the median and verges, high percentages of crops, and few obstructions to low flight.

Mortality hotspots along I-84/86 were generally devoid of low flying obstructions, so establishing barriers to low flight may be an effective technique to reduce barn owl-vehicle collisions. Reducing small mammals in verges and median vegetation could also potentially reduce barn owl mortality. Because I found fewer small mammals in areas with shrubs, establishing taller shrub vegetation may reduce small mammal habitat and reduce hunting success, encouraging owls to hunt elsewhere. Reducing wildlife-collisions involving barn owls in Idaho is important for motorist safety and would be an important step in ensuring the persistence of this avian species.

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LIST OF ABBREVIATIONS

AADT	Total Average Annual Daily Traffic
AIC	Akaike Information Criterion
CAADT	Commercial Average Annual Daily Traffic, also traffic volume
EB	Eastbound (i.e., EB verge = eastbound verge)
I-84	Interstate 84
I-86	Interstate 86
ITD	Idaho Transportation Department
PAADT	Passenger Average Annual Daily Traffic
ROW	Right-of-way
WB	Westbound (i.e., WB verge = westbound verge

CHAPTER ONE: FACTORS INFLUENCING BARN OWL (*TYTO ALBA*) ROADWAY MORTALITY AND CHARACTERISTICS OF MORTALITY HOTSPOTS ALONG INTERSTATE HIGHWAYS 84 AND 86, IDAHO

Introduction

Roads are an integral part of human society, and land transport of goods and people rely on road networks worldwide. Currently, there are more than 64 million kilometers of paved and unpaved roads on earth which equates to about 83 round-trips to the moon (CIA 2013, van der Ree et al. 2015). The United States (U.S.) alone has 6.5 million kilometers of roads (FHA 2013), and 83 percent of the continental U.S. is within one kilometer of a road (Riitters and Wickham 2003). The length of these roads and the number of vehicles that drive on them are projected to increase by 25 million kilometers and to 2.8 billion vehicles, respectively, by 2050 (Meyer et al. 2012, Dulac 2013).

These roads and vehicles, however, have detrimental effects on populations of many vertebrate and invertebrate taxa and landscapes. They reduce and degrade habitat, fragment landscapes, create noise and light pollution, and increase human influence on the landscape by allowing access to previously isolated areas (Brumm 2004, Fuller et al. 2007, Parris and Schneider 2008, Fahrig and Rytwinski 2009, Barber et al. 2010, Summers et al. 2011, Berthinussen and Altringham 2012, McClure et al. 2013, Strasser and Heath 2013, Barthelmess 2014, van der Ree et al. 2015, Ware et al. 2015). Furthermore, roads directly kill billions of animals each year via wildlife-vehicle collisions (Brown and Brown 2013). Populations of frogs and toads (Fahrig et al. 1995), turtles (*Chrysemys picta* and *Chelydra serpentina*, Steen and Gibbs 2004), and badgers (*Meles meles*, Clarke et al. 1998) decline near roads. Additionally, roadway collisions with wildlife put motorists at risk for injury, property damage, or even death (Kociolek at al. 2011).

Avoiding vehicle collisions is thus important for motorist safety, reducing collision expenditures, and ensuring the persistence of species inhabiting or using areas near roads. An important step in developing effective mitigation for road effects on wildlife is identifying high mortality zones (hotspots). It is not typically financially feasible to mitigate along an entire highway (Gomes et al. 2009), thus hotspot identification focuses mitigation practices on the most fatal sections (Gunson and Teixeira 2015). Additionally, monitoring known hotspots is equally as important to ensure mitigation strategies remain in suitable areas. A hotspot that has stayed consistent through time provides an obvious area for mitigation, but one that has shifted could indicate that mitigation should be aimed at the new hotspot. Equally important is the need to recognize the possibility that the historical hotspot could have been so fatal that it decreased the wildlife population in the area and thus no longer appears as a hotspot even though it would still be an important site for mitigation (Fahrig et al. 2001, Eberhardt et al. 2013).

While reducing wildlife-vehicle collisions with ungulates are often the focus of many highway programs, birds are often overlooked in mitigation planning (Kociolek et al. 2015). Loss et al. (2014) estimate that 89-340 million birds die annually from vehicle collisions on U.S. roads, whereas in Canada, an estimated 10 million birds die from vehicle collisions (Calvert et al. 2013). This indicates the enormity of road mortality of birds, and little is known about the potential for road mortality at these levels to influence population viability.

Among birds, vehicle collisions are particularly likely to kill barn owls (*Tyto alba*). Barn owls are frequently the most common species of road casualty when studies focus on recording multiple species of birds (Moore and Mangel 1996, Massemin and Zorn 1998, Ramsden 2003, Baudvin 2004, Gomes et al. 2009, Boves and Belthoff 2012). Moreover, some authors report vehicle-caused mortality is the major mortality factor in barn owls and accounts for 56-70 percent of deaths (Bunn et al. 1982, Newton et al. 1991, de Bruijn 1994, Taylor 1994, Shawyer 1998, Fajardo et al. 2000).

Alarmingly, an annual road mortality rate of as little as five percent can reduce the barn owl population to half the size it was originally before road mortality was applied to the population (Borda-de-Agua et al. 2014). Additionally, in England, where barn owl populations have suffered substantial declines in recent decades, proportion of road kills is on the rise. For instance, of the total barn owl population in England, the percentage of dead barn owls from road mortality increased from 6 percent in 1910-1954 and to 50% in 1991-1996 (Ramsden 2003). A roadway mortality rate of <1 owl/km/year caused local extirpation of barn owls in some areas. These findings are striking because Interstate 84 (I-84) in Idaho has one of the world's highest reported rates of mortality for barn owls from vehicular collisions (5.99 owls/km/year). This suggests the viability of the barn owl population in southern Idaho may be at risk (Boves and Belthoff 2012, Table 1.1).

Hundreds of barn owls are killed annually between Boise and Burley, Idaho along I-84 (Boves and Belthoff 2012, Pictures 1.1 and 1.2). Barn owls are killed more often on portions of the roadway closer to the Snake River Canyon, perhaps because of the availability of nest and roost sites, and barn owls are also killed significantly more often than expected when the highway traverses agricultural lands (Boves and Belthoff 2012).

There is marked seasonal as well as annual variation in barn owl-vehicle collisions. Owl mortality peaks in autumn/winter and varies annually. The latter is perhaps because of environmental conditions that affect prey abundance and/or owl reproduction (Boves and Belthoff 2012). Finally, barn owls in southern Idaho may exhibit well below the minimum productivity likely required for the population to persist without substantial immigration or decreases in roadway mortality (Boves and Belthoff 2012).

Although barn owl mortality occurs throughout many regions of I-84, Boves and Belthoff (2012) identified three areas of especially high mortality (Figure 1.1) near Hagerman, Kimberly, and Hazelton, Idaho. The three hotspots averaged 3.3 km in length. While these three hotspots comprised only four percent of the survey route, they contained >20 percent of dead barn owls. I wished to learn if and how the location or intensity of the mortality hotspots has changed since 2004-2006 (Boves and Belthoff 2012).

While Boves and Belthoff (2012) identified distance to the Snake River Canyon, presence of agricultural lands, and season as important influences on barn owl roadway mortality, there are many other potentially important factors that have not been investigated. For instance, volume of traffic, speed of vehicles, individual configuration of roads, and road density are among the most frequently mentioned factors affecting bird mortality on roads (Clevenger et al. 2003, Erritzoe et al. 2003, Holm and Laursen 2011, Kociolek et al. 2011). Distance to streams and other linear features can also be important (Shawyer 1998, Gomes et al. 2009, Boves and Belthoff 2012, Grilo et al. 2012), as well as vehicle size and number of traffic lanes (Massemin and Zorn 1998, Ramsden 2003, Baudvin 2004).

Additionally, Ramsden (2003) identified the presence/absence of continuous low flight obstructions as an important correlate of barn owl roadway mortality. Continuous low flight obstructions are any objects that might block the flight of a barn owl, such as human structures, trees, or berms. Barn owls hunt relatively low to the ground (approximately 1.5-4.5 m above the ground) in a low, sweeping fashion, and obstructions may force them to fly up and over the roadway (Shawyer 1998, Ramsden 2003). Elevation of the roadway (i.e., below or above the surrounding landscape) is also considered an important correlate (Ramsden 2003), as mortality rates are particularly high on roadways that are level with or elevated compared to the surrounding landscape (Baudvin 1997, Massemin and Zorn 1998, Lodé 2000, Ramsden 2003).

The presence or absence of grass verges is another potentially important factor related to barn owl roadway mortality. Verges are the patches of land that run adjacent to highways as opposed to the right-of-way (ROW) which includes everything between the two fences on either side of the highway. The ROW includes the verges, median, and vehicle lanes. These verges may harbor prey, which then potentially attracts barn owls to hunt along the roadway (Picture 1.3, Moore and Mangel 1996, Massemin and Zorn 1998, Ramsden 2003, Baudvin 2004, Gomes et al. 2009, Sabino-Marques and Mira 2011, Ascensao et al. 2012, Grilo et al. 2012, Grilo et al. 2014).

My goals were to clarify the spatial, roadway, and biotic factors associated with barn owl-vehicle collisions along I-84/86. I was also interested in examining if and how the intensity and locations of mortality hotspots have changed. To do so, I conducted road surveys to identify locations of barn owl-vehicle collisions; quantified spatial, roadway, and biotic factors along the focal highway to examine how they related to patterns of barn owl roadway mortality; and quantified mortality hotspots to examine temporal and spatial changes between 2004-2006 and 2013-2015. Reducing wildlife-collisions involving barn owls in Idaho is important for motorist safety and would be an important step in ensuring the persistence of this avian species.

Methods

Study Species

Barn owls have a worldwide distribution and occur in many portions of the U.S. where they occupy open habitats in both urban and rural settings and nest in trees, cliffs, caves, riverbanks, barn lofts, haystacks, and nest boxes. They are common in farmlands, grasslands, prairies, and deserts and fly slowly at night or dusk with slow wing beats and a looping, buoyant flight. Barn owls typically prey on small mammals including voles, mice, rats, moles, and shrews and hunt at night flying 1.5-4.5 m above the ground.

Barn owls have declined in parts of their range including the U.S. (Colvin 1985). Seven states (Connecticut, Illinois, Indiana, Iowa, Michigan, Missouri, and Ohio) list barn owls as threatened or endangered, and nine other states consider barn owls as a species of special concern. Possible reasons for population declines include changing agricultural practices reducing prey availability, rodenticides, and vehicle collisions (Marti et al. 2005, Hindmarch et al. 2012).

Study Area

I used locations of road-killed barn owls I recorded as well as the locations Boves and Belthoff (2012) recorded along 365-km of I-84/86 between Boise (43°37’N, 116°12’W) and Pocatello (42°52’N, 112°26’W) in southern Idaho (Figure 1.2). I-84/86 is a major four-lane roadway with two lanes in each direction with a vegetated median (13 – 100 m wide) separating the east and westbound lanes in most locations. The eastbound (EB) and westbound (WB) verges range from approximately 7 to 82 m wide between the pavement and the roadway fence. Elevation along I-84/86 ranges from ~ 800 m above sea level near Glenns Ferry, Idaho to 1,365 m near Pocatello, Idaho. The speed limit was 121 km/hour for cars and 105 km/hour for trucks throughout much of the study period but was raised to 129 km/hour and 113 km/hour, respectively, in July 2014. The area surrounding the I-84/86 corridor is characterized by shrub steppe, disturbed grasslands, and agricultural lands. The Snake River Canyon is within 1 km of the I-84/86 corridor at times and provides ample nest and roost sites for barn owls, in addition to those that occur in trees and human structures in some areas.

Survey Protocol

I performed standardized road surveys to locate dead barn owls along I-84/86 twice per month (approximately every two weeks) from October 2013 to September 2014 between Boise and Pocatello, Idaho (760 km round-trip). Additional ad hoc surveys occurred in March and April 2014, February 2015, and May 2015. Standardized surveys and ad hoc surveys were identical except that standardized surveys occurred consecutively at regular intervals (every two weeks). I ultimately combined observations from these surveys with previously collected barn owl roadkill data (Boves and Belthoff

2012) collected along I-84 primarily between Boise and Burley, Idaho (496 km round trip). Together these summed to 73 road surveys which provided locations of 1,335 dead barn owls for analysis. Because the landscape along the I-84/86 corridor had not undergone any major changes during the 10 years between survey periods (pers. observ.) I was able to combine the dead barn owl locations from both survey periods into one analysis.

Driving surveys for road-killed barn owls occurred during daylight hours and started in Boise, Idaho between 0700 – 0800 h. The time to complete a survey depended on (1) the number of owl carcasses detected and processed and (2) the length of I-84 surveyed, but surveys typically ended between 1800 – 2000 h. I conducted road kill surveys from a full-size pickup truck while traveling at approximately 88 km/hr. Two observers (including myself) scanned the roadsides for dead barn owls and recorded carcass locations using a Garmin handheld GPS unit. I stopped at the locations of all barn owl carcasses and removed them from the roadway to avoid double-counting in subsequent surveys. In addition, locations of all other road-killed mammals and other raptors were recorded.

Quantification of Spatial, Roadway, and Biotic Covariates

Measurement of Covariates

I initially grouped the covariates I measured into three categories based on how they described aspects of the landscape, highway, and biota that may potentially affect barn owl roadway mortality. I ultimately characterized nine spatial, 19 roadway, and nine biotic variables (Table 1.2).

To estimate small mammal abundance (included in biotic factors), I surveyed for small mammals in the median and vegetated roadside at 120 randomly located sites along I-84/86 between Boise and Burley, Idaho. I used a combination of camera traps and track traps from which I calculated a small mammal abundance index from camera images and footprints (see Appendix A for a detailed description of these methods). Using Wilcoxon Rank Sum Tests I compared mean small mammal abundance index between plant cover types in both the verges and median to determine in which plant cover type small mammals were more abundant. I established square buffers (Figure 1.3) of three different lengths (1-, 3-, and 5-km, Figure 1.4) that were centered on the 120 small mammal trapping sites using ArcMap 10.2 (ESRI 2012). I characterized spatial, roadway, and biotic variables for each of the 360 squares. Thirteen of these variables were not scale-dependent and were measured at the center of each square, while twenty-four were scale-dependent.

I used the National Land Cover Database (NLCD2011) raster layer which contained 16 land cover types to determine percent land cover category within each square size for the 120 trapping sites. These land cover types were open water, perennial snow/ice, developed open space, developed low intensity, developed medium intensity, developed high intensity, barren land, deciduous forest, evergreen forest, mixed forest, shrub/scrub, herbaceous, hay/pasture, cultivated crops, woody wetlands, and emergent herbaceous wetlands. I also used NLCD2011 to calculate the minimum, maximum, and average distance from the nearest agricultural field at each of the three scales using 100-m increments along the length of a given square (referred to as the 100-m method hereafter, Figure 1.5).

The Idaho Transportation Department (ITD) provided GIS data layers that summarized 2012 passenger vehicle average annual daily traffic (PAADT), commercial vehicle average annual daily traffic (CAADT), total average annual daily traffic (AADT), pavement type, pavement condition, speed limit, shoulder type EB/WB, left/right unpaved shoulder width EB/WB, left/right paved shoulder width EB/WB, total lane width EB/WB, total road width EB/WB, and total width of the right-of-way (ROW, Table 1.2). I extracted these data at each of the small mammal trapping sites (center of the square). I also calculated cumulative length of secondary roads (all roads—paved or dirt—within each of the squares) using data provided by ITD.

I calculated the number of dairies within each square and the minimum, maximum, and average distance from squares to the nearest dairy (calculated using the 100-m method). Registered dairies were defined as any establishment that sells milk for human consumption (data provided by Idaho State Department of Agriculture). I calculated minimum, maximum, and average distances to the nearest water feature from a given square (calculated using the 100-m method), average distance to Snake River Canyon (calculated using the 100-m method), and the total length of water features using 1996 data provided by Idaho Department of Water Resources. Slope was calculated using a digital elevation model (US Geological Survey EarthExplorer database). I used standard deviation of the slope for a given square as a measure of landscape heterogeneity. Lastly, human structures were manually digitized from which I calculated the percentage of land covered by human structures within each square.

Using Google Earth (2014) I manually measured width of the verge EB/WB, number of traffic lanes EB/WB, total number of traffic lanes, plant cover type in the

EB/WB verge, plant cover type in the median, habitat change past the fence adjacent to the highway EB/WB (yes or no, Figure 1.6), and embankments/excavations (Figure 1.7, Picture 1.4) along I-84/86 between Boise and Pocatello. I scored each using the 100-m method. I averaged within each square for width of the verge EB/WB and scored the mode for plant cover type in the EB/WB verge and in the median. For habitat change past the fence EB/WB, I calculated the percentage of 'yes' values for each square. I quantified embankments/excavations using an index that ranged from -2 to 2 at each 100-m segment (-2 = excavated > 5m, -1 = excavated 1-4m, 0 = level, 1 = embanked 1-4m, 2 = embanked > 5m) and averaged values for a given square.

Using Google Earth (2014), I manually measured obstructions and power lines along the sides of the interstate or in the median, as well as measured the width of the median. I operationally defined an obstruction as anything that may block the flight of an owl (i.e., trees, housing structures, excavated portions of the road, or others that were ≥ 5 m in height and ≤ 30 m of the road surface) and calculated the total length of these obstructions and powerlines for each square. Width of the median was measured at each of the trapping sites (center of the square).

Assessing Scale

The square buffers contained highway segments with lengths of 1-km (area = 100 ha), 3-km (area = 900 ha), and 5-km (area = 2,500 ha). The 1-km scale roughly reflects the typical foraging distance of a barn owl, whereas the 5-km scale approximates the maximum estimate of nightly barn owl movements (Marti et al. 2005). I evaluated the spatial, roadway, and biotic variables at each of the three scales in relation to the number of dead barn owls counted along 1- and 5-km highway segments to determine their respective best scales (either 1-, 3-, or 5-km) using Akaike Information Criterion (AIC_C, Figure 1.8). This approach produced two sets of models: the 1-km highway segment model set and the 5-km highway segment model set.

Modeling of Site Covariates

I ultimately removed variables from analysis after assessing covariates for redundancy, multicolinearity, best scale, and model parsimony (Tables 1.3 and 1.4) and produced a final variable set for analysis that included 14 variables for both the 1- and 5-km model sets (Tables 1.5 and 1.6). These included four spatial, five roadway, and five biotic variables. I assessed the potential effects of all possible combinations of these variables within each set on number of dead barn owls in 1- and 5-km highway segments using Generalized Linear Models (Poisson distribution, Log link function, log transformed number of surveys as the offset, and including an overdispersion parameter when necessary) within an AIC_C information theoretic model selection framework (Burnham and Anderson 2002).

I combined the variables from the top models in each variable set into a final set in which I assessed all possible combinations (a total of eight variables for the 1-km set and seven variables for the 5-km set). I ultimately model averaged them into a final model for the 1-km set, whereas model averaging was not necessary for the 5-km set. Models I selected for averaging were limited to those within 2 AIC_C of the top model (Burnham and Anderson 2002, Grueber et al. 2011). However, nested models (i.e., more complex versions of the model with the lowest AIC_C) within 2 AIC_C were removed before model averaging (Richards 2008, Arnold 2010, Grueber et al. 2011). One of the variables in the final 1-km model (width of the median) was further analyzed using a

Spearman's Rank Correlation analysis to determine its relationship with percent land cover type.

Mortality Hotspots

Point Density Estimation

Using a point density estimation analysis in ArcMap, Boves and Belthoff (2012) reported three hotspots each 3-4 km in length near the towns of Hagerman, Kimberly, and Hazelton, Idaho. I used a similar approach for analysis of data I collected in 2013-2015 and visually compared areas of peak mortality to evaluate temporal changes. I also combined data from all survey time periods to produce maps of longer-term mortality hotspots. I considered hotspots locations with mortality rates of 5.24-10.67 owls/km/year following criteria used by Boves and Belthoff (2012). I did not adjust mortality rates for search (observer's ability to detect), removal (scavenger removal), or crippling (barn owl struck but died elsewhere) biases. Boves and Belthoff (2012) suggest that actual mortality rates are 2-4 times higher when these biases can be considered. Because survey methods were consistent between the two survey periods (2004-2006 and 2013-2015), I did not expect the bias to change spatially, and thus it should not influence my identification of hotspots or analysis of the covariates.

Kernel Density Estimation Program (KDE+)

Because point density estimation analysis can be subjective and does not allow statistical inference concerning hotspots, I also used the program KDE+ (Bil et al. 2013) to examine whether hotspots had significantly higher rates of mortality than other areas of the focal highway. KDE+ relies on kernel density estimation, and significant hotspots are areas where the kernel density function exceeds the significance level corresponding to the 95th percentile level estimated using Monte Carlo simulations (Bil et al. 2013). KDE+ also provided a measure of strength for each resulting hotspot ranging from 0 to 1, with 1 being the most dense, i.e., hottest, location. I used ArcMap (ESRI 2012) to display the mortality clusters produced from KDE+ and considered hotspots as those sites with strengths of 0.6-1. I used the range 0.6-1 as this was similar to the range used by Boves and Belthoff (2012) in the point density analysis (5.24-10.67 owls/km/year) allowing for visual comparison between these two hotspot analyses.

Characteristics of Hotspots and Non-Hotspots

I calculated which of the 120 trapping sites were in a hotspot using the combined data point density estimation analysis (2004-2006 and 2013-2015). I compared characteristics of hotspots and non-hotspots for the 14 spatial, roadway, and biotic variables selected for final modeling (see above) using Wilcoxon Rank Sum Tests or Fisher's Exact Tests.

Statistical Analysis

Unless otherwise noted, all statistical analyses were completed using JMP 12.0 (SAS Institute, Cary, North Carolina) or R (R Core Team 2013). I present means ± SD throughout unless noted. I considered comparisons significant when $p < 0.05$.

Results

Barn Owl Road Kill Data (2013-2015)

I completed 24 standardized road surveys along I-84/86 between Boise and Pocatello, Idaho from October 2013 to September 2014 and recorded 106 dead barn owls. Number of dead barn owls varied temporally with the largest number of carcasses in winter months (December through February; Figure 1.9). Ad hoc surveys between March

2013 and May 2015 located an additional 444 dead barn owls (Table 1.7). Dead barn owls observed on ad hoc surveys were allowed to accumulate (unlike standardized surveys in which dead barn owls were regularly removed from the highway every two weeks) as they were singular surveys in which double-counting of dead barn owls was not of concern. The accumulation of dead barn owls on ad hoc surveys did not pose a problem for the purposes of my analyses as only the location of the dead barn owls was necessary and not the rate of barn owl roadway mortality. Of almost 2,200 roadkill carcasses that I counted along I-84/86, barn owls were not only the most numerous bird of prey species, but they outnumbered all other species (Table 1.8). Seven other species of raptors were also among the road-killed animals (Table 1.8).

Characteristics of 120 Sample Sites

Spatial, roadway, and biotic characteristics of the 120 segments for each of the three scales (1-, 3-, and 5-km) exhibited sufficient variability to examine their potential influence on patterns of barn owl road mortality (Tables 1.9-1.11 and Figures 1.10-1.11). When combining data from both survey periods (2004-2006 and 2013-2015) for the 120 1-km segments, the number of dead barn owls per segment averaged 5.0 ± 6.1 (range: 0 – 25; Figure 1.12). For the 5-km segments, the number of dead barn owls per segment was 24 ± 26.3 (range: 0 - 98, Figure 1.13).

The small mammal abundance index ranged from 0-6 and averaged 4.8 ± 1.5 at the 120 trapping sites (Figure 1.14). Only three sites (2.5 percent) lacked rodents (i.e., index = 0), whereas 53 sites (44.2 percent) had the greatest index value of 6. Thus, species that contribute to the rodent prey of barn owls were generally abundant at most of the 120 trapping sites along I-84/86 (Figure 1.15). Additionally, the small mammal abundance index was greater when the roadside verges and median had grass plant cover type (Table 1.12, Figure 1.16).

Variable Reduction and Final Variable Set

Ultimately, I removed variables from the candidate set for analysis (Tables 1.3 and 1.4). Among the 14 remaining variables in the 1-km model set (Table 1.5) were four spatial (distance to Snake River Canyon, distance to nearest water feature, number of dairies, and cumulative length of roads), five roadway (homogeneity of slope, cumulative length of obstructions, pavement type, CAADT, and width of the median), and five biotic variables (abundance index, cover type verge, cover type median, percentage crop, and percentage human structures). The same 14 variables remained in the 5-km model set except that cumulative length of water feathers replaced distance to nearest water feature (Table 1.6).

Factors Affecting Barn Owl Roadway Mortality at the 1-km Scale

Within the spatial, roadway, and biotic variable model sets, there were two, two, and three models, respectively, within 2 AIC_C of the lowest AIC_C value, and all were substantially lower than their respective null and global models (Tables 1.13-1.15). Two variables from the spatial set, three from the roadway set, and three from the biotic set continued on to the final model set. The final model set therefore consisted of these eight spatial, roadway, and biotic variables for which I examined all possible combinations. This produced nine models within 2 AIC_C of the lowest AIC_C value, and all were substantially lower than the null and global models (Table 1.16). Screening for nested models removed models 2, 3, 4, 6, and 7 (Table 1.17), which resulted in a final set of four models (Table 1.18). These four models contained six variables (cumulative length of roads, CAADT, width of median, plant cover type verge, small mammal abundance index, and percentage human structures), which I model-averaged (Table 1.19).

The number of dead barn owls/1-km segment/survey decreased as the percentage human structures, cumulative length of roads, and width of median increased (Table 1.19, Figure 1.17). Percent land cover type varied with the width of the median (Figure 1.18) in that the median was generally wider when the highway was surrounded by shrubs (Spearman's Rank Correlation, $r_s = 0.30$, $p < 0.001$) and narrower when surrounded by crops ($r_s = -0.24$, $p = 0.009$). Finally, the number of dead barn owls/1-km segment/survey increased with CAADT, small mammal abundance index, and when the plant cover type verge was grass (Table 1.19, Figure 1.17).

Factors Affecting Barn Owl Roadway Mortality at the 5-km Scale

Within the spatial, roadway, and biotic model sets, one, two, and three models, respectively, were within 2 AIC_C of the lowest AIC_C value, and all were substantially lower than their respective null and global models (Tables 1.20-1.22). One variable from the spatial set, three from the roadway set, and three from the biotic set continued on to the final model set. The final model set therefore consisted of these seven spatial, roadway, and biotic variables for which I examined all possible combinations. This produced four models within 2 AIC_C of the lowest AIC_C value and all were substantially lower than the null and global models (Table 1.23). Screening for nested models removed models 2, 3, and 4 (Table 1.24), which resulted in one final model (Table 1.25). This final model contained a single variable (percentage crops), in which the number of dead barn owls/5-km segment/survey increased as the percentage of crops increased (Table 1.26, Figure 1.19).

Mortality Hotspots

Point Density Hotspot Locations

The hotspots identified in 2004-2006 (Boves and Belthoff 2012) occurred between Bliss and Hazelton, Idaho and were a combined length of 5.6 km accounting for 117 of 785 (14.9 percent) barn owl carcasses in the 248-km length of I-84 between Boise and Burley, Idaho (Table 1.27, Figure 1.20).The hotspots I identified for 2013-2015 occurred between Bliss and Hagerman, Idaho and were a combined length of 8.0 km accounting for 79 of 550 (14.4 percent) barn owl carcasses detected in the 380-km length of I-84/86 between Boise and Pocatello, Idaho (Table 1.27, Figure 1.20). When pooling data from all survey years, hotspots remained between Bliss and Hazelton, Idaho and were a combined length of 11.8 km accounting for 250 of 1,335 (18.7 percent) barn owl carcasses (Table 1.27, Figure 1.21). Mortality of barn owls occurred in the areas leading into and out of these hotspots, as well as in other areas of the surveyed portions of I-84/86, but at somewhat lower rates (Figures 1.22 and 1.23).

Temporal Changes in Point Density Hotspots between Survey Periods

While barn owl mortality along I-84/86 continued to be widespread, my road kill surveys and those of Boves and Belthoff (2012) were consistent in identifying the section of highway between Bliss and Hazelton, Idaho as that of greatest mortality (Figures 1.20-1.23). The magnitude of barn owl mortality decreased somewhat in the hotspot regions that Boves and Belthoff (2012) described as #2 and #3, although I recorded barn owl carcasses in these locations during 2013-2015 (Figure 1.20). Hotspot #1 described by Boves and Belthoff (2012) expanded such that it appeared with two components (Figure 1.20). Additionally, the landscape along the I-84/86 corridor, including in the regions of the hotspots, underwent few if any major changes during the 10 years between survey periods (Figure 1.24).

KDE+ Hotspot Locations

When I re-analyzed the 2004-2006 roadkill data, KDE+ produced 30 clusters with strengths ranging from 0.03 to 0.70 (Table 1.28, Figure 1.25). The two highest strengths corresponded to two clusters within what was described as hotspot #3 in the 2004-2006 point density analysis (Figure 1.20). Roadkill data from the more recent 2013-2015 surveys produced 10 clusters with strengths ranging from 0.29 to 0.73 (Table 1.29, Figure 1.26). The highest strength corresponded to hotspot #1A in the 2013-2015 point density analysis (Figure 1.20). The combined data (2004-2006 and 2013-2015) produced 43 clusters with strengths ranging from 0.0003 to 0.71 (Table 1.30, Figure 1.27). The highest strengths corresponded with hotspots #3 and #1A from the 2004-2006 and 2013-2015 point density analysis (Figure 1.20), consistent with the previous KDE+ results.

Furthermore, although hotspot #2 in the 2004-2006 point density analysis appeared on the map to be larger and potentially more detrimental to barn owls, KDE+ results indicated that hotspot #3 was of higher mortality strength. Hotspot #3 was a shorter mortality zone than hotspot #2 (0.5 km vs. 3.3 km, respectively); thus after adjusting for length, hotspot #3 killed a higher number of barn owls in a shorter distance than hotspot #2 and therefore received a higher mortality strength (Table 1.28).

Temporal Changes in KDE+ Hotspots between Survey Periods

The KDE+ analysis produced similar hotspots as the point density method, with the highest mortality zones still between Bliss and Hazelton, Idaho along I-84 (Figures 1.20-1.23). Similar to the point density analysis, the magnitude of barn owl mortality decreased in the hotspot regions that Boves and Belthoff (2012) described as #2 and #3 and increased in the region they described as #1 (Figures 1.25-1.27).

Characteristics of Hotspots and Non-Hotspots

Based on the combined point density estimate maps (2004-2006 and 2013-2015), six trapping sites were in mortality hotspots and 114 sites outside of hotspots (Figures 1.28-1.30). For the spatial variables, sites in mortality hotspots were generally close to the Snake River Canyon or other water features, had low cumulative road lengths, and had few dairies (Table 1.31, Figure 1.28). For roadway variables, mortality hotspots had higher levels of CAADT, low slopes, fewer kilometers of low flight obstructions, narrow medians, and flexible rather than rigid pavement type (Tables 1.31 and 1.32, Figure 1.29, Pictures 1.5-1.9). Among the biotic variables, trapping sites in hotspot locations had small mammal abundance index values that ranged from 2 to 6, as none of the hotspot sites lacked rodents (index = 0), whereas some sites outside hotspot locations that had index values = 0 or 1 (Figure 1.30). Lastly, hotspots generally had grass rather than mixed shrubs in both the verges and median, high percentages of crops, and low percentages of human structures (Tables 1.31 and 1.32, Figure 1.30, Pictures 1.5-1.9).

Discussion

Barn Owl Road Mortality Surveys

Similar to Boves and Belthoff (2012) and other studies (Moore and Mangel 1996, Massemin and Zorn 1998, Ramsden 2003, Baudvin 2004, Gomes et al. 2009), barn owls were not only the most numerous bird species I detected during road surveys of I-84/86 in 2013-2015, but they outnumbered all other bird and mammal species encountered. Barn owls outnumbered the next most common species (skunk, *Mephitis mephitis*) by four times. I also observed seasonal variation in barn owl carcasses along this interstate with the highest numbers during winter months, which is similar to Boves and Belthoff (2012) for southern Idaho and others studying barn owls elsewhere (Glue 1971, Moore and Mangel 1996, Newton et al. 1997). Patterns in results of my 2013-2015 barn owl mortality surveys were thus consistent with those observed by Boves and Belthoff (2012) in the 2004-2006 surveys despite the nearly 10 year span between survey periods.

Spatial, Roadway, and Biotic Covariates

After assessing a suite of spatial, roadway, and biotic features potentially associated with barn owl-vehicle collisions I found that the results from the 1-km and 5-km model sets were consistent with other studies of factors that affect barn owl road mortality. For instance, barn owl carcasses along I-84/86 increased with higher CAADT. Traffic volume is as an important factor in the magnitude of barn owl road mortality in many regions typically with higher mortality in areas with greater traffic (Massemin et al. 1998, Ramsden 2003, Grilo et al. 2014). Interestingly, Massemin et al. (1998) suggested the increase in barn owls killed during the autumn and winter months may be the result of concordance between the onset of barn owl hunting activity and peak traffic volume. That is, in winter months the onset of rush hour traffic and peak owl mortality both occur just after sunset. Additionally, Ramsden (2003) suggested vehicle size was also an important factor in that larger vehicles were more detrimental to barn owls because of their low-flight hunting behavior. Furthermore, Ojeda et al. (2015) suggested the turbulence created by large vehicles may also increase owl deaths. The fact that I found that CAADT (commercial truck traffic, i.e., larger vehicles) was more associated with the number of dead barn owls than PAADT (passenger vehicle traffic i.e., smaller vehicles) suggests that vehicle size may also be important along I-84 and turbulence created by truck traffic may indeed increase barn owl roadway mortality. Barn owls may also be less able to escape a larger vehicle, such as a truck, than a smaller passenger vehicle.

Additionally, I found that the number of barn owl carcasses decreased with cumulative length of secondary roads, percentage of human structures, and width of the median increased. Barn owls are associated with agricultural lands and thus less likely to occur in areas with high percentages of human structures and secondary roads (Regan 2016). Therefore, as these features increased along the roadway, barn owl carcasses decreased. The negative association with width of the median and barn owl carcasses could also have been driven by the land cover in the surrounding landscapes. Along the survey route, the median was generally wider when the surrounding landscape was comprised by shrubs and, conversely, narrower when the surrounding landscape was dominated by agricultural lands. Barn owls are associated with agricultural lands; thus, as the median became wider in shrub lands, barn owl carcasses decreased.

The positive relationship I observed between percentage of crops and number of dead barn owls at the 5-km scale could indicate that scale is important. That is, it is possible that percentage crops did not make the final variable set in the 1-km model set because finer scale variables (e.g., plant cover type in the verge, width of median, small mammal abundance index) were more important. When I increased the length of highway segments along which number of dead barn owls were analyzed to 5-km, it appears these finer scale variables dropped out of the final model set leaving the larger scale variable, percentage of crops. However, in both model sets crops were important whether directly (as in the 5-km model set) or indirectly through other variables (width of median, percentage human structures, cumulative length of secondary roads) in the 1-km model set.

I believe that the above results highlight the general propensity for barn owls to inhabit farmlands. Land cover type was also an important factor in Portugal where Gomes et al. (2009) found that dead barn owls were negatively associated with development as well as with pine (*Pinus* sp.) forest habitat. Grilo et al. (2012) found that proximity of highly suitable barn owl habitat i.e., crops near the highway, was an important factor influencing locations of dead owls. Lastly, in France, Massemin and Zorn (1998) also found the majority of barn owls were killed in areas that crossed open fields. Thus, there is a common pattern that appears to include road collisions in agricultural lands with which my findings are also congruent.

Finally, I found barn owl carcasses increased with higher small mammal abundance index values. This indicates barn owls may be attracted to portions of the highway for hunting prey. Barn owl mortality was also higher when there was grass in the roadside verges when compared with sites where plant cover type was shrubs. As I found the small mammal abundance index was greater in grass verses mixed shrubs sites, this could reflect the suitability of grassy areas for both small mammals and owl hunting as well as the decrease of barn owl hunting ability in areas with taller shrubs.

Small mammals along the verges of highways appear to be important influences on barn owl mortality in many regions (Moore and Mangel 1996, Massemin and Zorn 1998, Ramsden 2003, Baudvin 2004, Gomes et al. 2009, Grilo et al. 2012, Grilo et al. 2014), although few previous studies have quantified small mammals directly. Grilo et al. (2012) reported that barn owls were killed in higher numbers in locations where verges offered suitable habitat and barn owls would be more likely to encounter small mammals. This may also partially explain some of the seasonality observed in barn owl mortalities (increase in autumn and winter) in both southern Idaho and elsewhere. It is likely that croplands provide good habitat for small mammals and good hunting for barn owls for a large portion of spring and summer. But in autumn and winter, small mammal populations in fields may be greatly reduced and barn owls may choose other suitable areas to hunt, including grassy verges and road medians (Sabino-Marques and Mira 2011, Ascensao et al. 2012, Regan 2016, Figure 1.31).

Mortality Hotspots

Temporal Changes in Hotspot Locations

The section of I-84/86 area between Bliss and Hazelton, Idaho again had the highest rates of barn owl-vehicle collisions. Hotspot #1 from the 2004-2006 surveys remained consistent and appeared to expand into what I categorized as hotspots #1A and #1B -. Conversely, hotspots #2 and #3 from the 2004-2006 survey period decreased in size in the 2013-2015 surveys. It is possible that mortality in the latter locations could have shifted to other locations (i.e., #1A and #1B), or perhaps mortality rates in these hotspots were so high that they decreased the local barn owl population in the area and no longer appear as hotspots. For instance, Fahrig et al. (2001) found that as the traffic volume increased through the years of their study, the number of road-killed frogs and toads decreased, which suggested that the wildlife populations decreased around the high mortality zone and thus resulted in fewer road kills. Additionally, Eberhardt et al. (2013) found that with increasing traffic volume the number of anuran road kills decreased. They argued that given the main effect of roads on anurans is mortality, and not road avoidance, the population had likely decreased in the high mortality zones such that they no longer appeared as high mortality zones because of fewer road kills from a decreased population. Eberhardt et al. (2013) thus concluded hotspots should be used with caution when identifying the best locations for mitigation.

Following Eberhardt et al. (2013), I believe that there are two lines of evidence that hotspots #2 and #3 are still important potential zones of high barn owl mortality despite no longer appearing as hotspots in the 2013-2015 surveys. First, while the population status of barn owls in southern Idaho is unknown, and their behavior near roads remains largely unstudied (e.g., road avoidance as in anurans, Eberhardt et al. 2013), the literature on barn owls indicates that they do not avoid roads (Grilo et al. 2012). Thus, I hypothesize that mortality would still continue in these locations if barn owls were still plentiful near them. Second, a reduced hotspot could potentially be explained by changes in the landscape features so that the areas are less suitable over time to support the wildlife population. However, the local landscape along the I-84 corridor in the regions of the hotspots did not undergo major change between the two survey periods. Given these factors, hotspots #2 and #3 may still be important mortality zones and important for future mitigation consideration as the hotspots potentially have reduced the barn owl population in these areas.

While KDE+ analysis produced similar hotspots as point density analysis, there were slight differences between the two methods. For instance, hotspot #2 appeared to be more detrimental in the point density analysis whereas KDE+ identified hotspot #3 as that of higher barn owl mortality. This illustrates the importance in choosing techniques to evaluate hotspots as different techniques may produce different results (Snow et al.

2014). One advantage of the KDE+ analysis for identifying hotspots was that it allowed for statistical inference. However, each method I used allowed for comparison of hotspots between survey periods.

Characteristics of Hotspots and Non-Hotspots

Comparisons between characteristics of sites located within and outside of hotspots detected just two variables (road length and CAADT) that differed significantly. However, hotspots were generally situated close to the Snake River Canyon, were near water features, had low slopes (level terrain), narrow medians, flexible rather than rigid pavement type, and did not contain the highest number of dairies. The hotspots were also in regions of I-84/86 with high traffic volume, low percentage of human structures surrounding them, few secondary roads, moderate to high small mammal abundance, grass plant cover types in the median and verges, and a high percentage of crops.

Furthermore, as hotspots also had few kilometers of obstructions to low flight and barn owls hunt relatively low to the ground, flight behavior is a critical factor in barn owl roadway mortality (Shawyer 1998, Massemin and Zorn 1998, Ramsden 2003, Gomes et al. 2009, Grilo et al. 2014). As barn owls do not appear to avoid roads (Grilo et al. 2012), barn owls hunting along the highway are flying at roughly the same height as vehicles, which increases their likelihood of being hit by traffic. Establishing obstructions to low flight, therefore, could be a way to force barn owls to fly up and safely over the highway (Ramsden 2003).

Management Implications

Though the literature is lacking in formal studies on the efficacy of reducing barn owl-vehicle collisions, several studies have hypothesized measures that may be effective

(Table 1.33). Based on suggestions in the literature and my study results, I believe the following mitigation strategies may be relevant to reducing barn owl vehicle collisions along the I-84/86 corridor in southern Idaho. The highest priority locations for mitigation along I-84/86 likely would be the area between Bliss and Hazelton, Idaho (Figures 1.16 and 1.17) which contains four hotspots (#s 1A, 1B, 2, 3). The areas surrounding these hotspots also kill owls, so extending mitigation beyond the immediate boundaries of each hotspot would likely help reduce barn owl-vehicle collisions as well.

As mortality hotspots along I-84 are generally devoid of low flying obstructions establishing barriers to low flight may be an effective technique to reduce barn owl-vehicle collisions. Barriers could be hedges or trees, bird netting, fences, earthen berms or any other features that would cause owls to fly higher. Reducing small mammals in verges and median vegetation could also potentially reduce barn owl mortality. Because I found fewer small mammals in areas with shrubs, establishing taller shrub vegetation may reduce small mammal habitat and simultaneously decrease the ‘huntability’ for barn owls (de Bruijn 1994, Mead 1997, Baudvin 2004, Gomes et al. 2009, Grilo et al. 2012). This may be achieved by cutting roadside vegetation less frequently or planting suitable taller shrub vegetation in areas of high barn owl mortality. Alternatively, frequent mowing to keep vegetation low to reduce cover and forage for small mammals might also make these areas less attractive for small mammals and thus barn owls.

Summary and Conclusions

My research indicates that barn owl-vehicle collisions have continued in high numbers along I-84/86. Indeed, during 2004-2006, Boves and Belthoff (2012) detected as many as 105 dead barn owls during a single road survey conducted between Boise and

Burley, Idaho. In a single ad hoc survey, I found 230 dead barn owls between Boise and Pocatello during my research. After my research, a different ad hoc survey conducted over a year after the conclusion of my standardized surveys found 303 dead barn owls between Boise and Pocatello, Idaho (pers. observ.). It is important to note that barn owls had been accumulating through the winter months in which barn owl mortality peaks.

While mortality occurs in many portions of I-84/86 between Boise and Pocatello, there were areas where the rate of barn owl-vehicle collisions was especially high. A number of these areas had barn owl mortality rates >5 owls/km/year, which I categorized as mortality hotspots. The general locations of hotspots were similar between the 2004-2006 and 2013-2015 study periods, although there have been some expansions and contractions. The area between Bliss and Hazelton, Idaho remained the section of I-84/86 containing the greatest mortality of barn owls despite a span of 10 years between studies.

High numbers of dead barn owls across two multi-year studies conducted about a decade apart indicates that the high mortality rate is not a one-time incident. Rather, it is an ongoing concern along this interstate highway. Furthermore, the fact that collision hotspots have remained similar over this duration indicates that these specific road segments are the areas of greatest concern. Constructing barriers to low flight and/or reducing small mammal habitat along the verges and median would likely help reduce barn owl-vehicle collisions and help ensure persistence of the barn owl population in southern Idaho.

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Tables

Table 1.1 Direct mortality of barn owls along roads.

Rate of Barn Owl Mortality (owls/100 km/year)	Location	Source
0.7	Germany	Illner (1992)
7.0	Switzerland	Bourquin (1983)
25.0	France	Massemin and Zorn (1998)
43.4	California	Shulz (1986)
49.0	Portugal	Gomes et al. (2009)
48 – 96	Portugal	Grilo et al. (2012)
64.1	Great Britain	Taylor (1994)
185.6	California	Moore and Mangel (1996)
Up to 260.9	Idaho	Boves and Belthoff (2012)

Table 1.2 Spatial, roadway, and biotic variables measured along Interstate-84/86 in southern Idaho in relation to barn owl road mortality.

Variable	Description	Units
Spatial		
Elevation	Average calculated by measuring elevation every 100-m within square	m
Distance to Nearest Agricultural Field (min, avg, center)	Average and minimum distance to nearest agricultural field calculated by measuring every 100-m within square; Center measured from center of square	km
Distance to Snake River Canyon (min, avg, center)	Average and minimum distance to Snake River Canyon calculated by measuring every 100-m within square; Center measured from center of square	km
Distance to Nearest Bridge/Overpass (min, avg, center)	Average and minimum distance to nearest bridge or overpass calculated by measuring every 100-m within square; Center measured from center of square	km
Distance to Nearest Water Feature (min, avg, center)	Average and minimum distance to nearest water feature (stream, river, canal, lake, reservoir, or other water feature) calculated by measuring every 100-m within square; Center measured from center of square	km
Distance to Nearest Dairy (min, avg, center)	Average and minimum distance to nearest commercial dairy calculated by measuring every 100-m within square; Center measured from center of square	km

Number of Dairies	Number of dairies within square	#
Cumulative Length of Water Features	Cumulative length of water features within square	km
Cumulative Length of Roads other than I-84	Cumulative length of roads within square	km
Roadway		
Embankment/ Excavation	Road surface relative to surrounding landscape scored: -2 (excavated > 5 m), -1 (excavated 1 - 4 m), 0 (level), 1 (embanked 1 - 4m), 2 (embanked > 5 m), measured every 100-m within square and averaged	Index
Homogeneity of Slope	Standard deviation of slope calculated from a Digital Elevation Model (DEM) in GIS	%
Cumulative Length of Obstructions	Start/End of obstructions (trees, structures, excavated portions of highway, and others to potentially block low flight of owls, ≥ 5 m tall and within 30 m of highway); cumulative length within square and summed for EB/WB/Median	km
Cumulative Length of Power Lines	Start/End of power lines; cumulative length within square and summed for EB/WB/Median	km
Pavement Type	Extracted from ITD GIS layer; Flexible, Rigid	Nominal
AADT	Average Annual Daily Traffic extracted from ITD GIS layer	#
CAADT	Commercial Average Annual Daily Traffic extracted from ITD GIS layer	#
PAADT	Passenger Average Annual Daily Traffic extracted from ITD GIS layer	#
Traffic Lanes EB/WB	Extracted from ITD GIS layer	#
Total Number of Traffic Lanes	Extracted from ITD GIS layer, sum of EB/WB	#
Traffic Speed	Extracted from ITD GIS layer	km/h
Width of EB/WB verge	Average calculated by measuring every 100-m within square	m
Width of Median	Measured at center of square	m
Pavement Condition	Extracted from ITD GIS layer; Good, Fair, or Poor calculated by measuring every 100-m within square	Nominal
Shoulder Type EB/WB	Extracted from ITD GIS layer; Surfaced with bituminous material, Surfaced with tied PCC, Surfaced with PCC measuring every 100-m within square	Nominal
Left/Right Unpaved Shoulder Width EB/WB	Extracted from ITD GIS layer measuring every 100-m within square	m
Left/Right Paved Shoulder Width EB/WB	Extracted from ITD GIS layer measuring every 100-m within square	m
Total Lane Width EB/WB	Extracted from ITD GIS layer measuring every 100-m within square	m

Total Road Width EB/WB	Extracted from ITD GIS layer measuring every 100-m within square	m
Biotic		
Small Mammal Abundance Index	Calculated from camera and track trapping at 120 sites	Index
Plant Cover Type in the EB/WB Verges	Mode calculated from measurements every 100-m within square; Grass (G), Mixed Shrub (M)	Nominal
Plant Cover Type in the Median	Mode calculated from measurements every 100-m within square; Grass (G), Mixed Shrub (M)	Nominal
Habitat Change Past Fence EB/WB verge	Percentage of 'Yes' values calculated from measurements every 100-m within square (see text)	%
Percentage of Crop	Percentage of crop within square calculated from National Land Cover Database (NLCD2011)	%
Percentage of Shrub	Percentage of shrub within square calculated from National Land Cover Database (NLCD2011)	%
Percentage of Human Structures	Percentage of human structures within square; Manually digitized using GIS	%
Percentage of Developed	Total percentage of development within square calculated from National Land Cover Database (NLCD2011)	%
Percentage of Open Water	Percentage of open water within square calculated from National Land Cover Database (NLCD2011)	%

Table 1.3 Variables removed and reason for removal for statistical analysis in 1-km models.

Variable	**Reason for Removal**
Spatial	
Elevation	Model parsimony
Distance to Nearest Agricultural Field (min, avg, center)	Avg lower AIC_C than min and center (164.20 vs. 167.20 vs. 168.51); Correlated with % Crop (-0.71); higher AIC_C (162.31 vs. 164.29)
Distance to Snake River Canyon (avg, center)	Min lower AIC_C than avg and center (183.00 vs. 183.69 vs. 183.77)
Distance to Nearest Bridge (min, avg, center)	Captured in Obstructions dataset
Distance to Nearest Water Feature (avg, center)	Min lower AIC_C than avg and center (165.49 vs. 169.19 vs. 169.69)
Distance to Nearest Dairy (min, avg, center)	Center lower AIC_C than avg and min (198.77 vs. 199.20 vs. 202.09); Number of Dairies lower AIC_C (159.90 vs. 198.77); Number of Dairies chosen as dairy measurement
Cumulative Length of Water Features	Distance Nearest Water Feature lower AIC_C (165.49 vs. 165.60); Distance Nearest Water Feature chosen as water measurement
Roadway	
Embankment/Excavations	Correlated with Obstructions (-0.72); higher AIC_C (164.24 vs. 164.99)

Cumulative Length of Power Lines	Model parsimony
AADT	Correlated with CAADT (0.72) and PAADT (0.99); CAADT lowest AIC$_C$ (153.15 vs. 172.94 vs. 176.12)
PAADT	Correlated with CAADT (0.60) and AADT (0.99); CAADT lowest AIC$_C$ (153.15 vs. 172.94 vs. 176.12)
Number of Traffic Lanes EB/WB	No variability
Total Number of Traffic Lanes	No variability
Traffic Speed	No variability
Width of EB/WB Verge	EB and WB correlated (0.71); EB lower AIC$_C$ (164.40 vs. 179.95); EB correlated with % Crop (-0.64); Lower AIC$_C$ (162.30 vs. 164.40) but % Crop chosen as crop measurement
Pavement Condition	Model parsimony
Shoulder Type EB/WB	Model parsimony
Left/Right Unpaved Shoulder Width EB/WB	No variability
Left/Right Paved Shoulder Width EB/WB	No variability
Total Lane Width EB/WB	No variability
Total Road Width EB/WB	No variability
Biotic	
Plant Cover Type in the EB Verge	EB higher AIC$_C$ than WB (167.38 vs. 159.19); Cover Type Verge (WB) chosen as verge plant cover type measurement
Plant Cover Type Change Past Fence EB/WB Verge	EB and WB correlated (0.87); EB lower AIC$_C$ (172.35 vs. 182.73); Correlated with % Crop (0.72); higher AIC$_C$ (172.35 vs. 162.31); kept % Crop; Correlated with Distance to Snake River Canyon (-0.73); lower AIC$_C$ (172.35 vs. 183.00) but kept Distance to Snake River Canyon
Total Percentage of Shrub	Correlated with % Crop (-0.97); lower AIC$_C$ (160.83 vs. 162.31) but kept % Crop
Total Percentage of Developed	Correlated with % Human Structures (0.91); higher AIC$_C$ (166.23 vs. 164.50)
Total Percentage of Open Water	Correlated with Slope (0.68); Distance to Nearest Water Feature chosen as water measurement

Table 1.4 Variables removed and reason for removal for statistical analysis in 5-km models.

Variable	Reason for Removal
Spatial	
Elevation	Model parsimony
Distance to Nearest Agricultural Field (min, avg, center)	Avg lower AIC_C than min and center (131.22 vs. 140.02 vs. 141.76); Correlated with % Crop (-0.71); higher AIC_C (131.22 vs. 121.03)
Distance to Snake River Canyon (min, center)	Avg lower AIC_C than min and center (154.05 vs. 154.70 vs. 154.87)
Distance to Nearest Bridge (min, avg, center)	Captured in Obstructions dataset
Distance to Nearest Water Feature (avg, min, center)	Min lower AIC_C than avg and center (143.80 vs. 146.30 vs. 146.37); higher AIC_C than Cumulative Water Length (143.80 vs. 143.12); Cumulative Water Length chosen as water measurement
Distance to Nearest Dairy (avg, min, center)	Avg lower AIC_C than min and center (158.36 vs. 158.82 vs. 159.34); higher AIC_C than Number of Dairies (158.36 vs. 136.38); Number of Dairies chosen as dairy measurement
Roadway	
Embankment/Excavations	Correlated with Obstructions (-0.72); higher AIC_C (141.91 vs. 140.18)
Cumulative Length of Power Lines	Model parsimony
AADT	Correlated with CAADT (0.72) and PAADT (0.99); CAADT lowest AIC_C (125.8086)
PAADT	Correlated with CAADT (0.60) and AADT (0.99); CAADT lowest AIC_C (125.8086)
Number of Traffic Lanes EB/WB	No variability
Total Number of Traffic Lanes	No variability
Traffic Speed	No variability
Width of EB/WB Verge	EB and WB correlated (0.71); EB lower AIC_C (128.5097 vs. 129.1901); EB correlated with % Crop (-0.64); higher AIC_C (128.51 vs. 121.03) than % Crop; kept % Crop
Pavement Condition	Model parsimony
Shoulder Type EB/WB	Model parsimony
Left/Right Unpaved Shoulder Width EB/WB	No variability
Left/Right Paved Shoulder Width EB/WB	No variability
Total Lane Width EB/WB	No variability
Total Road Width EB/WB	No variability
Biotic	

Plant Cover Type in the EB Verge	EB higher AIC_C than WB (141.28 vs. 137.24); Cover Type Verge (WB) chosen as verge plant cover type measurement
Plant Cover Type Change Past Fence EB/WB Verge	EB and WB correlated (0.87); WB lower AIC_C (136.88 vs. 140.83); Correlated with % Crop (0.72); higher AIC_C (136.88 vs. 121.03); kept % Crop; Correlated with Distance to Snake River Canyon (-0.77); lower AIC_C (136.88 vs. 154.70) but kept Distance to Snake River Canyon
Total Percentage of Shrub	Correlated with % Crop (-0.97); higher AIC_C (121.03 vs. 122.32)
Total Percentage of Developed	Correlated with % Human Structures (0.91); higher AIC_C (144.16 vs. 141.99)
Total Percentage of Open Water	Cumulative Water Length chosen as water measurement

Table 1.5 Final spatial, roadway, and biotic variables for modeling in 1-km model set.

Variable Name	Variable Description	Scale	Range
Spatial			
Distance to Snake River Canyon (min)	Minimum distance to Snake River Canyon measured every 100 m within 5 km square	Km	0.004 to 47.8
Distance to Nearest Water Feature (min)	Minimum distance to nearest water feature measured every 100 m within 5 km square	Km	0 to 2.2
Number of Dairies	Number of dairies within 5 km square	Count	0 to 14
Cumulative Road Length	Cumulative length of secondary roads within 1 km square	Km	2.5 to 18.8
Roadway			
Commercial Average Annual Daily Traffic	Commercial Vehicle Average Annual Daily Traffic measured at center of square	vehicles/year	2100 to 5300
Pavement Type	Pavement Type measured at center of square	categorical	flexible or rigid
Homogeneity of Slope	Standard deviation of slope within 1 km square	%	2.4 to 22.1
Cumulative Length of Obstructions	Cumulative length of obstructions in 1 km square	Km	0 to 2
Width of Median	Width of the median measured at center of square	M	13 to 100
Biotic			
Small Mammal Abundance Index	Small mammal abundance index measured at center of square	--	0 to 6
Plant Cover Type Verge	Mode of verge plant cover type measured every 100 m within 1 km square	categorical	mixed, grass, or shrub

Plant Cover Type Median	Mode of median plant cover type measured every 100 m within 3 km square	categorical	mixed or grass
% Crop	% crop land within 3 km square	%	0 to 91.9
% Human Structures	% human structures within 5 km square	%	0 to 32.5

Table 1.6 Final spatial, roadway, and biotic variables for modeling in 5-km model set.

Variable Name	Variable Description	Scale	Range
Spatial			
Distance to Snake River Canyon (avg)	Average distance to Snake River Canyon measured every 100 m within 1 km square	Km	0.4 to 48.6
Cumulative Length of Water Features	Cumulative length of water features within 1 km square	Km	0 to 2.7
Number of Dairies	Number of dairies within 5 km square	Count	0 to 14
Cumulative Road Length	Cumulative length of secondary roads within 1 km square	Km	2.5 to 18.8
Roadway			
Commercial Average Annual Daily Traffic	Commercial Vehicle Average Annual Daily Traffic measured at center of square	vehicles/year	2100 to 5300
Pavement Type	Pavement Type measured at center of square	categorical	flexible or rigid
Homogeneity of Slope	Standard deviation of slope within 5 km square	%	2.6 to 23.4
Cumulative Length of Obstructions	Cumulative length of obstructions in 1 km square	Km	0 to 2
Width of Median	Width of the median measured at center of square	M	13 to 100
Biotic			
Small Mammal Abundance Index	Small mammal abundance index measured from center of square	--	0 to 6
Plant Cover Type Verge	Mode of verge habitat measured every 100 m within 1 km square	categorical	mixed, grass, or shrub
Plant Cover Type Median	Mode of median habitat measured every 100 m within 3 km square	categorical	mixed or grass
% Crop	% crop land within 3 km square	%	0 to 91.9
% Human Structures	% human structures within 5 km square	%	0 to 32.5

Table 1.7 Road-killed barn owls recorded during ad hoc surveys along I-84/86 in southern Idaho.

Month/Year	Survey Route	Number of Barn Owls
March 2013	Boise to Wendell, I-84	123
March 2013	Boise to Pocatello, I-84/86	230
February 2015	Boise to Pocatello, I-84/86	29
May 2015	Boise to Pocatello, I-84/86	62
	Total	444

Table 1.8 Number and species of bird and mammal carcasses found on I-84 in southern Idaho during standardized and ad hoc road surveys (2013-2015).

Count	Scientific Name	Common Name
550	*Tyto alba*	Barn owl
143	*Mephitis mephitis*	Striped skunk
142	*Sylvilagus* spp. *or Lepus* spp.	Cottontail or jackrabbit
139	*Canis latrans*	Coyote
107	*Felis silvestris catus*	Domestic cat
104	*Odocoileus hemionus* or *virginianus*	Mule deer or white-tailed deer
63	*Procyon lotor*	Raccoon
59	*Bubo virginianus*	Great horned owl
58	*Marmota flaviventris*	Yellow-bellied marmot
42	*Spermophilus* spp.	Ground squirrel
33	*Vulpes*	Red fox
33	*Taxidea taxus*	American badger
18	*Buteo jamaicensis*	Red-tailed hawk
14	*Larus* spp.	Gull
12	*Erethizon dorsaum*	Porcupine
11	*Phasianus colchicus*	Ring-necked pheasant
11	*Buteo swainsoni*	Swainson's hawk
9	*Columba livia*	Rock pigeon
8	*Anas platyrhynchos*	Mallard
6	*Pica hudsonia*	Black-billed magpie
4	*Canis lupus familiaris*	Domestic dog
3	*Corvus brachyrhynchos*	American crow
3	*Branta canadensis*	Canada goose
2	*Corvus corax*	Common raven
2	*Megascops kennicottii*	Western screech-owl
1	*Cervus canadensis*	Elk

1	*Callipepla californica*	California quail
1	*Agelaius phoeniceus*	Red-winged blackbird
1	*Euphagus cyanocephalus*	Brewer's blackbird
1	*Accipiter striatus*	Sharp-shinned hawk
1	*Circus cyaneus*	Northern harrier
1	*Falco sparverius*	American kestrel
538	***	Unknown mammal
45	***	Unknown bird
12	***	Unknown snake
2178	***Total***	

Table 1.9 *Spatial* characteristics of the 120 small mammal trapping sites along I-84/86 in southern Idaho at the trapping site and within 1-, 3-, and 5-km square buffers centered on the trapping site.

Variable	**Center of Square** **$\bar{x}$ ± SD** **(min – max)**	**1-km Square** **$\bar{x}$ ± SD** **(min – max)**	**3-km Square** **$\bar{x}$ ± SD** **(min – max)**	**5-km Square** **$\bar{x}$ ± SD** **(min – max)**
Elevation (m)	–	1068 ± 170 (765 – 1365)	1068 ± 168 (768 – 1360)	1067 ± 168 (768 – 1357)
Minimum Distance to Agricultural Field (km)	–	0.37 ± 0.71 (0.0 – 3.90)	0.21 ± 0.47 (0.0 – 3.19)	0.12 ± 0.29 (0.0 – 2.0)
Average Distance to Agricultural Field (km)	–	0.51 ± 0.79 (0.01 – 3.94)	0.53 ± 0.71 (0.02 – 3.77)	0.52 ± 0.64 (0.02 – 3.33)
Center Distance to Agricultural Field (km)	0.51 ± 0.82 (0.00 – 3.92)	–	–	–
Minimum Distance to Snake River Canyon (km)	–	13.49 ± 14.94 (0.10 – 48.44)	12.95 ± 14.96 (0.00 – 48.12)	12.49 ± 14.94 (0.00 – 47.82)
Average Distance to Snake River Canyon (km)	–	13.79 ± 14.91 (0.40 – 48.61)	13.76 ± 14.92 (0.45 – 48.44)	13.74 ± 14.92 (0.46 – 48.26)
Center Distance to Snake River Canyon (km)	13.78 ± 14.91 (0.46 – 48.62)	–	–	–
Minimum Distance to Bridge/Overpass (km)	–	1.23 ± 1.32 (0.00 – 6.46)	0.48 ± 0.94 (0.00 – 5.08)	0.18 ± 0.57 (0.00 – 3.70)
Average Distance to Bridge/Overpass (km)	–	1.80 ± 1.35 (0.20 – 6.93)	1.71 ± 1.15 (0.42 – 6.26)	1.63 ± 0.99 (0.50 – 5.57)
Center Distance to Bridge/Overpass (km)	1.83 ± 1.41 (0.00 – 7.14)	–	–	–
Minimum Distance to Nearest Water Feature (km)	–	0.53 ± 0.79 (0.00 – 4.03)	0.24 ± 0.53 (0.00 – 2.95)	0.13 ± 0.36 (0.00 – 2.24)

Average Distance to Nearest Water Feature (km)	–	0.80 ± 0.83 (0.05 – 4.42)	0.78 ± 0.74 (0.08 – 3.94)	0.76 ± 0.67 (0.16 – 3.59)
Center Distance to Nearest Water Feature (km)	0.83 ± 0.86 (0.00 – 4.69)	–	–	–
Minimum Distance to Nearest Dairy (km)	–	9.47 ± 7.90 (0.32 – 33.21)	8.69 ± 7.74 (0.10 – 32.00)	8.01 ± 7.53 (0.10 – 30.80)
Average Distance to Nearest Dairy (km)	–	9.94 ± 7.94 (0.66 – 33.87)	9.93 ± 7.92 (0.73 – 33.56)	9.95 ± 7.86 (0.87 – 32.99)
Center Distance to Nearest Dairy (km)	9.93 ± 7.95 (0.62 – 33.88)	–	–	–
Center Distance to Nearest Dairy (km)	9.93 ± 7.95 (0.62 – 33.88)	–	–	–
Cumulative Length of Water Features (km)	–	0.61 ± 0.76 (0.00 – 2.68)	5.77 ± 4.18 (0.00 – 14.71)	16.11 ± 9.57 (0.00 – 35.43)
Cumulative Length of Roads other than I-84/86 (km)	–	8.09 ± 3.82 (2.54 – 18.79)	37.71 ± 18.13 (8.59 – 99.82)	84.78 ± 42.35 (15.78 – 250.69)

Table 1.10 *Roadway* characteristics of the 120 trapping sites along I-84/86 in southern Idaho.

Variable	**Center of Square** $\bar{x}$ **± SD** **(min – max)**	**1-km Square** $\bar{x}$ **± SD** **(min – max)**	**3-km Square** $\bar{x}$ **± SD** **(min – max)**	**5-km Square** $\bar{x}$ **± SD** **(min – max)**
Embankment/Excavations EB	–	0.56 ± 0.52 (-1.55 – 1.09)	0.51 ± 0.44 (-1.65 – 1.13)	0.50 ± 0.39 (-1.24 – 1.25)
Embankment/Excavations WB	–	0.68 ± 0.58 (-2.00 – 1.36)	0.51 ± 0.44 (-1.65 – 1.13)	0.64 ± 0.41 (-1.06 – 1.20)
Homogeneity of Slope (5)	–	4.95 ± 3.05 (2.35 – 22.09)	5.95 ± 3.92 (2.50 – 24.32)	7.04 ± 4.66 (2.62 – 23.36)
Cumulative Length of Obstructions (km)	–	0.27 ± 0.47 (0.00 – 2.53)	0.93 ± 1.27 (0.00 – 7.64)	1.68 ± 2.04 (0.00 – 10.96)
Cumulative Length of Power Lines (km)	–	0.55 ± 0.69 (0.00 – 2.54)	1.65 ± 1.72 (0.00 – 6.10)	2.81 ± 2.62 (0.00 – 9.00)
AADT	–	15635 ± 3947 (6400 – 21500)	15635 ± 3947 (6400 – 21500)	15635 ± 3947 (6400 – 21500)
CAADT	–	4584 ± 837 (2100 – 5300)	4584 ± 837 (2100 – 5300)	4584 ± 837 (2100 – 5300)
PAADT	–	11051 ± 3391 (4300 – 16300	11051 ± 3391 (4300 – 16300	11051 ± 3391 (4300 – 16300
Traffic Speed Passenger Vehicles (km/h)	–	121 ± 0 (121 – 121)	121 ± 0 (121 – 121)	121 ± 0 (121 – 121)
Traffic Speed	–	105 ± 0	105 ± 0	105 ± 0

Commercial Vehicles (km/h)		(105 – 105)	(105 – 105)	(105 – 105)
Width of EB Verge (m)	–	22.1 ± 8.8 (7.0 – 53.3)	26.5 ± 12.7 (8.7 – 82.1)	25.8 ± 10.5 (10.0 – 65.6)
Width of WB Verge (m)	–	22.6 ± 9.4 (8.0 – 66.3)	27.2 ± 12.9 (9.2 – 82.1)	26.8 ± 10.3 (10.0 – 59.0)
Width of Median (m)	24.9 ± 15.0 (13.0 – 100.0)	–	–	–
Left/Right Unpaved Shoulder Width EB and WB (m)	0 ± 0 (0 – 0)	0 ± 0 (0 – 0)	0 ± 0 (0 – 0)	0 ± 0 (0 – 0)
Left Paved Shoulder Width EB and WB (m)	1.22 ± 0 (1.22 – 1.22)	1.22 ± 0 (1.22 – 1.22)	1.22 ± 0 (1.22 – 1.22)	1.22 ± 0 (1.22 – 1.22)
Right Paved Shoulder Width EB and WB (m)	3.05 ± 0 (3.05 – 3.05)	–	–	–
Total Lane Width EB and WB (m)	7.3 ± 0 (7.3 – 7.3)	–	–	–
Total Road Width EB and WB (m)	11.6 ± 0 (11.6 – 11.6)	–	–	–
Total Width of ROW (m)	97.6 29.3 (58 – 218)	–	–	–

Table 1.11 *Biotic* characteristics of the 120 small mammal trapping sites along I-84/86 in southern Idaho.

Variable	**Center of Square $\bar{x}$ ± SD (min – max)**	**1-km Square $\bar{x}$ ± SD (min – max)**	**3-km Square $\bar{x}$ ± SD (min – max)**	**5-km Square $\bar{x}$ ± SD (min – max)**
Small Mammal Abundance Index	4.78 ± 1.47 (0 – 6)	–	–	–
Habitat Change Past Fence EB Verge	–	65.9 ± 43.7 (0 – 100)	64.2 ± 42.8 (0 – 100)	64.1 ± 42.5 (0 – 100)
Habitat Change Past Fence WB Verge	–	64.8 ± 46.1 (0 – 100)	65.0 ± 43.8 (0 – 100)	64.5± 43.5 (0 – 100)
Percentage of Crop	–	39.6 ± 35.5 (0.0 – 87.3)	40.2 ± 35.6 (0.0 – 91.9)	39.9 ± 33.8 (0.0 – 91.1)
Percentage of Shrub	–	41.7 ± 38.2 (0.0 – 92.2)	47.4 ± 38.5 (0.0 – 96.0)	49.2 ± 37.0 (0.0 – 97.6)
Percentage of Human Structures	–	2.1 ± 5.9 (0.0 – 46.3)	2.7 ± 6.1 (0.0 – 41.9)	2.5 ± 4.8 (0.0 – 32.5)
Percentage of Developed	–	18.2 ± 8.3 (7.8 – 58.2)	11.5 ± 9.5 (4.0 – 56.4)	9.9 ± 7.7 (2.4 – 47.4)
Percentage of Open Water	–	0.5 ± 2.0 (0.0 – 16.1)	0.9 ± 2.3 (0.0 – 12.4)	1.1 ± 2.1 (0.0 – 10.3)

Table 1.12 Wilcoxon Rank Sum Test results comparing the small mammal abundance index in plant cover types in the EB/WB verges and median. '*' indicates $p < 0.05$).

Variable	W	p-value
EB Verge Plant Cover Type	1507	0.01*
WB Verge Plant Cover Type	2255	<0.001*
Median Plant Cover Type	1056.5	0.28

Table 1.13 1-km model set: Top models within the *spatial* model set. Null model: $AIC_C = 164.72$ Global model: $AIC_C = 203.01$.

#	Model	k	AIC_C	ΔAIC_C	w_i
1	Distance to Nearest Water Feature, Cumulative Road Length	4	154.39	0	0.57
2	Cumulative Road Length	3	155.33	0.94	0.36

Table 1.14 1-km model set: Top models within the *roadway* model set. Null model: $AIC_C = 164.72$, Global model: $AIC_C = 175.21$.

#	Model	k	AIC_C	ΔAIC_C	w_i
1	CAADT	3	153.15	0	0.39
2	Pavement Type, Width of Median	4	153.89	0.74	0.27

Table 1.15 1-km model set: Top models within the *biotic* model set. Null model: $AIC_C = 164.72$, Global model: $AIC_C = 168.91$.

#	Model	k	AIC_C	ΔAIC_C	w_i
1	Plant Cover Type Verge	3	159.19	0	0.24
2	Small Mammal Abundance Index, Plant Cover Type Verge	4	160.09	0.90	0.15
3	Plant Cover Type Verge, % Human Structures	4	161.06	1.87	0.10

Table 1.16 1-km model set: Top 9 models within *final* model set. Null model = AIC_C = 164.72, Global model: AIC_C = 168.92.

#	Model	k	AIC_C	ΔAIC_C	w_i
1	% Human Structures, Plant Cover Type Verge, CAADT, Cumulative Road Length	6	147.79	0	0.10
2	Small Mammal Abundance Index, % Human Structures, Plant Cover Type Verge, CAADT, Cumulative Road Length	7	147.96	0.17	0.09
3	% Human Structures, Plant Cover Type Verge, CAADT, Cumulative Road Length, Distance to Nearest Water Feature	7	148.58	0.79	0.07
4	Small Mammal Abundance Index, % Human Structures, Plant Cover Type Verge, CAADT, Cumulative Road Length, Distance to Nearest Water Feature	8	148.60	0.81	0.07
5	Small Mammal Abundance Index, Plant Cover Type Verge, CAADT, Cumulative Road Length	6	149.01	1.22	0.05
6	% Human Structures, Plant Cover Type Verge, CAADT, Width of Median, Cumulative Road Length	7	149.04	1.25	0.05
7	Small Mammal Abundance Index, % Human Structures, Plant Cover Type Verge, CAADT, Width of Median, Cumulative Road Length	8	149.39	1.60	0.04
8	% Human Structures, Width of Median, Cumulative Road Length	5	149.60	1.81	0.04
9	Plant Cover Type Verge, CAADT, Cumulative Road Length	5	149.63	1.84	0.04

Table 1.17 1-km model set: Nested models removed from the *final* model set. Bolded variables are those that were added to the base model creating a nested model removed from analysis.

#	Model	Retained in Model Set	Reason for Removal
1	% Human Structures, Plant Cover Type Verge, CAADT, Cumulative Road Length	✓	Base model; not removed
2	***Small Mammal Abundance Index***, % Human Structures, Plant Cover Type Verge, CAADT, Cumulative Road Length	×	Added Small Mammal Abundance Index to base model
3	% Human Structures, Plant Cover Type Verge, CAADT, Cumulative Road Length, ***Distance to Nearest Water Feature***	×	Added Distance to Nearest Water Feature to base model

4	***Small Mammal Abundance Index***, % Human Structures, Plant Cover Type Verge, CAADT, Cumulative Road Length, ***Distance to Nearest Water Feature***	×	Added Small Mammal Abundance Index and Distance to Nearest Water Feature to base model
5	Small Mammal Abundance Index, Plant Cover Type Verge, CAADT, Cumulative Road Length	✓	Unique model; not removed
6	% Human Structures, Plant Cover Type Verge, CAADT, ***Width of Median***, Cumulative Road Length	×	Added Width of Median to base model
7	***Small Mammal Abundance Index***, % Human Structures, Plant Cover Type Verge, CAADT, ***Width of Median***, Cumulative Road Length	×	Added Small Mammal Abundance Index and Width of Median to base model
8	% Human Structures, Width of Median, Cumulative Road Length	✓	Unique model; not removed
9	Plant Cover Type Verge, CAADT, Cumulative Road Length	✓	Unique model; not removed

Table 1.18 1-km model set: Top 4 models after nested models were removed from the *final* model set. Null model: $AIC_C = 164.72$, Global model: $AIC_C = 168.92$.

#	Model	k	AIC_C	ΔAIC_C	w_i
1	% Human Structures, Plant Cover Type Verge, CAADT, Cumulative Road Length	6	147.79	0	0.10
2	Small Mammal Abundance Index, Plant Cover Type Verge, CAADT, Cumulative Road Length	6	149.01	1.22	0.05
3	% Human Structures, Width of Median, Cumulative Road Length	5	149.60	1.81	0.04
4	Plant Cover Type Verge, CAADT, Cumulative Road Length	5	149.63	1.83	0.04

Table 1.19 1-km model set: Model-averaged coefficients.

Parameter	Model-Averaged Estimate	Weighted Unconditional Standard Error	95% CI Upper	95% CI Lower
Intercept	-4.56	1.98	-0.69	-8.43
% Human Structures	-0.02	0.03	0.03	-0.07
Plant Cover Type Verge	-0.14	0.14	0.13	-0.40
CAADT	0.0007	0.0004	0.002	-0.00003
Cumulative Road Length	-0.18	0.03	-0.12	-0.24
Small Mammal Abundance Index	0.02	0.03	0.08	-0.05
Width of Median	-0.005	0.008	0.01	-0.02

Table 1.20 5-km model set: Top models within the *spatial* model set. Null model: $AIC_C = 142.73$, Global model: $AIC_C = 169.34$.

#	Model	k	AIC_C	ΔAIC_C	w_i
1	Cumulative Road Length	3	134.09	0	0.65

Table 1.21 5-km model set: Top models within the *roadway* model set. Null model: $AIC_C = 142.73$, Global model: $AIC_C = 144.97$.

#	Model	k	AIC_C	ΔAIC_C	w_i
1	Pavement Type, Width of Median	5	124.20	0	0.45
2	CAADT	3	125.81	1.61	0.20

Table 1.22 5-km model set: Top models within the *biotic* model set. Null model: $AIC_C = 142.73$, Global model: $AIC_C = 132.49$.

#	Model	k	AIC_C	ΔAIC_C	w_i
1	% Crop	3	121.03	0	0.39
2	Small Mammal Abundance Index, % Crop	5	122.72	1.69	0.17
3	Plant Cover Type Verge, % Crop	5	123.02	1.99	0.14

Table 1.23 5-km model set: Top 4 models within *final* model set. Null model = AIC$_C$ = 142.73, Global model: AIC$_C$ = 163.05.

#	Model	k	AIC$_C$	ΔAIC$_C$	w_i
1	% Crop	3	121.03	0	0.20
2	Pavement Type, % Crop	5	121.46	0.43	0.16
3	Small Mammal Abundance Index, % Crop	5	122.72	1.69	0.09
4	Plant Cover Type Verge, % Crop	5	123.02	1.99	0.07

Table 1.24 5-km model set: Nested models removed from the top *final* model set. Bolded variables are those that were added to the base model creating a nested model removed from analysis.

#	Model	Retained in Model Set	Reason for Removal
1	% Crop	✓	Base model
2	***Pavement Type***, % Crop	×	Added Pavement Type to base model
3	***Small Mammal Abundance Index***, % Crop	×	Added Small Mammal Abundance Index to base model
4	***Plant Cover Type Verge***, % Crop	×	Added Plant Cover Type Verge to base model

Table 1.25 5-km model set: Top model after nested models were removed from the *final* model set. Null model: AIC$_C$ = 142.73, Global model: AIC$_C$ = 163.05.

#	Model	k	AIC$_C$	ΔAIC$_C$	w_i
1	% Crop	3	121.03	0	0.20

Table 1.26 5-km model set: Final model coefficients.

Parameter	Estimate	Standard Error	95% CI Upper	95% CI Lower
Intercept	-1.81	0.18	-2.18	-1.49
% Crop	0.07	0.003	0.01	0.02

Table 1.27 Characteristics of barn owl mortality hotspots along I-84 in southern Idaho.

Zone	Location	Approximate Mile Markers	Length of Zone (km)	No. of Owl Carcasses	% of Total Route	% of Total Carcasses
Years: 2004 – 2006						
1	8 km N of Hagerman, ID	144 to 145	1.8	27	0.8	3.4
2	8 km NE of Kimberly, ID	179 to 181	3.3	76	1.4	9.7
3	2.5 km SE of Hazelton, ID	190 to 191	0.5	14	0.2	1.8
Years: 2013 – 2015						
1A	8 km N of Hagerman, ID	143 to 145	3.5	38	1.0	6.9
1B	6 km NW of Wendell, ID	150 to 154	4.5	41	1.2	7.5
Years: 2004 – 2015 Combined						
1/1A	8 km N of Hagerman, ID	143 to 145	3.5	83	1.0	6.2
1B	6 km NW of Wendell, ID	150 to 154	4.5	64	1.2	4.8
2	8 km NE of Kimberly, ID	179 to 181	3.3	87	0.9	6.5
3	2.5 km SE of Hazelton, ID	190 to 191	0.5	16	0.1	1.2

Table 1.28 KDE+ clusters (n = 30) identified for the 2004-2006 period. Strength can be between 0-1, with 1 being the strongest, or hottest, location.

Cluster Number	Strength	Cluster Number	Strength
1	0.03	16	0.33
2	0.10	17	0.35
3	0.14	18	0.38
4	0.21	19	0.39
5	0.21	20	0.42
6	0.21	21	0.43
7	0.23	22	0.43
8	0.26	23	0.45
9	0.28	24	0.46
10	0.29	25	0.48
11	0.29	26	0.51
12	0.30	27	0.52
13	0.32	28	0.54
14	0.33	29	0.63
15	0.33	30	0.70

Table 1.29 KDE+ clusters (n=10) identified for the 2013-2015 period.

Cluster Number	Strength
1	0.29
2	0.32
3	0.40
4	0.43
5	0.48
6	0.49
7	0.50
8	0.51
9	0.51
10	0.73

Table 1.30 KDE+ clusters (n=43) identified for both survey periods combined (2004-2006 and 2013-2015).

Cluster Number	Strength	Cluster Number	Strength
1	0.0003	23	0.32
2	0.09	24	0.33
3	0.15	25	0.34
4	0.15	26	0.36
5	0.16	27	0.37
6	0.16	28	0.37
7	0.18	29	0.38
8	0.19	30	0.40
9	0.19	31	0.41
10	0.22	32	0.43
11	0.23	33	0.44
12	0.24	34	0.45
13	0.23	35	0.47
14	0.24	36	0.48
15	0.25	37	0.48
16	0.26	38	0.51
17	0.26	39	0.51
18	0.26	40	0.51
19	0.27	41	0.60
20	0.27	42	0.66
21	0.29	43	0.71
22	0.29		

Table 1.31 Wilcoxon Rank Sum Test results comparing characteristics between hotspots (n = 6) and non-hotspots (n = 114). '*' indicates p <0.05).

Variable	W	p-value
Spatial		
Distance to Snake River Canyon	365	0.79
Distance to Nearest Water Feature	276.5	0.43
Number of Dairies	258	0.21
Cumulative Road Length	613	0.001*
Roadway		
CAADT	600	0.002*
Homogeneity of Slope	262	0.34
Cumulative Length of Obstructions	257	0.27
Width of Median	402	0.47
Biotic		
Small Mammal Abundance Index	431	0.26
% Crop	214	0.12
% Human Structures	337	0.96

Table 1.32 Fisher's Exact Test results comparing characteristics between hotspots and non-hotspots. '*' indicates p < 0.05).

Variable	p-value	95% Confidence Interval Lower	95% Confidence Interval Upper	Odds Ratio
Roadway				
Pavement Type	0.09	0	1.54	0
Biotic				
Plant Cover Type Verge	0.05	0.75	63.83	5.50
Plant Cover Type Median	0.59	0	4.94	0

Table 1.33 Mitigation approaches to reduce or prevent barn owl-vehicle collisions from the published literature.

1. Vegetation Management to Reduce Rodents and/or Discourage Owl Hunting			
	Regular grass cutting to reduce voles	The Netherlands	de Bruijn (1994)
	Allow rank vegetation to grow thickly (e.g., brambles) to reduce prey and discourage hunting	Great Britain	Mead (1997)
	Allow bramble or gorse to spread across entire width of ROW to reduce voles and discourage owl hunting	Great Britain	Ramsden (2003)
	Stop systematic mowing so that brambles, thorns, and broom will take over grassy areas and discourage owl hunting	France	Baudvin (2004)
	Reduce prey near roads by changing vegetation or removing it by plowing	Portugal	Grilo et al. (2012)
2. Barriers to Flight			
	Allow hedges to grow high on roadsides to force owls to flying higher above road	Great Britain	Shawyer (1998)
	Create continuous 2-3 m hedges immediately next to roads to force owls to fly higher	Great Britain	Ramsden (2003)
	Regardless of whether trees or shrubs are used, any continuous low-flight obstruction (e.g., fence) would force birds to fly higher over roads and reduce mortality	Great Britain	Ramsden (2003)
	Forcing barn owls to fly high by minimum hedgerow height or narrow band of trees of at least 4 m	Canada/ Great Britain	Garland (2002) cited in Preston and Powers (2006)
	Diversion poles or short fences along highway medians and verges.		Jacobson (2005)
3. Create Suitable Habitat Elsewhere			
	Reduce owl prey in areas of highway or *enhance it elsewhere*	Portugal	Gomes et al. (2009)
	Establish complementary corridors of suitable grassland outside the ROW parallel to road exclusion fence on both sides	Portugal	Grilo et al. (2012)
4. Reduce Traffic Speed			
	Speed rather than density of traffic important for owl mortality, so reduce traffic speed	Germany	Illner (1992)

	Over 100 times as many barn owls killed on major roads with high vehicle speeds, so reduced speeds potentially could save owls	England	Ramsden (2003)

Figures

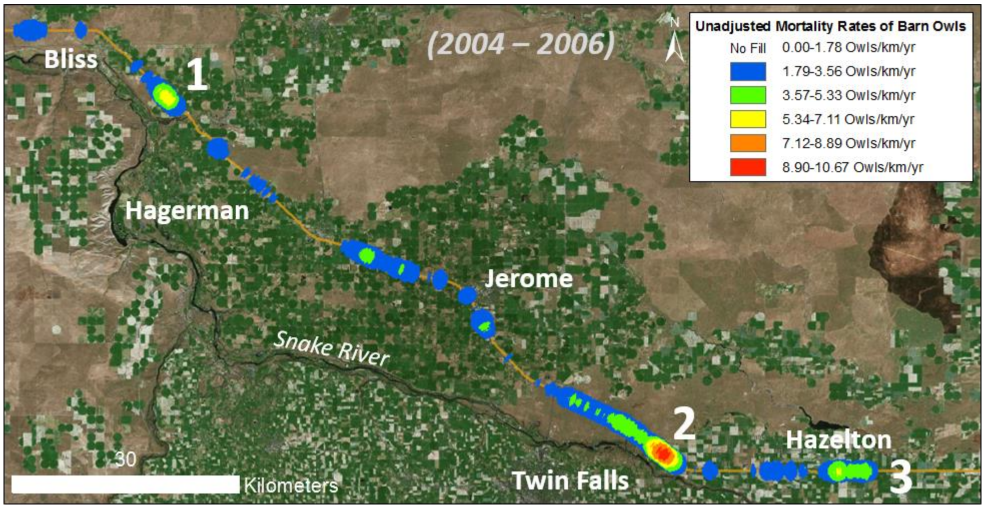


Figure 1.1 Density map of barn owl mortality locations along Interstate-84 between Hagerman and Hazelton, Idaho. Three peak mortality areas and the relative location of the Snake River are shown (adapted from Boves and Belthoff 2012).

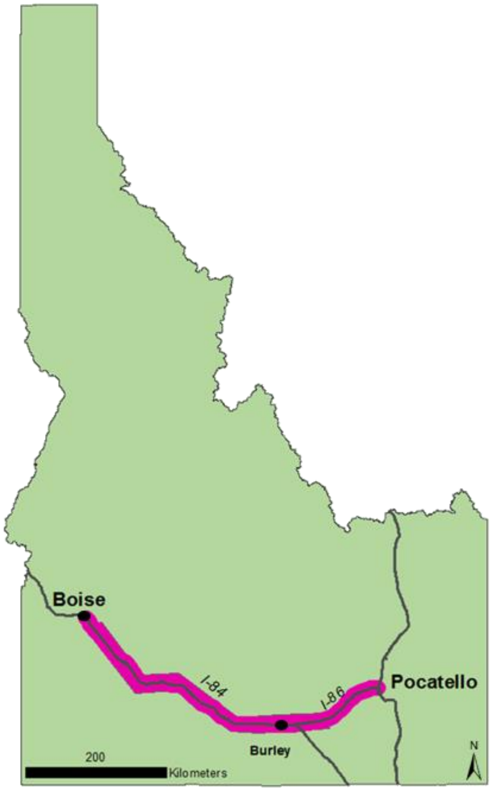


Figure 1.2 Map of I-84/86 survey route in southern Idaho for the 2013-2015 survey period. Surveys during 2004-2006 were primarily between Boise and Burley, Idaho.

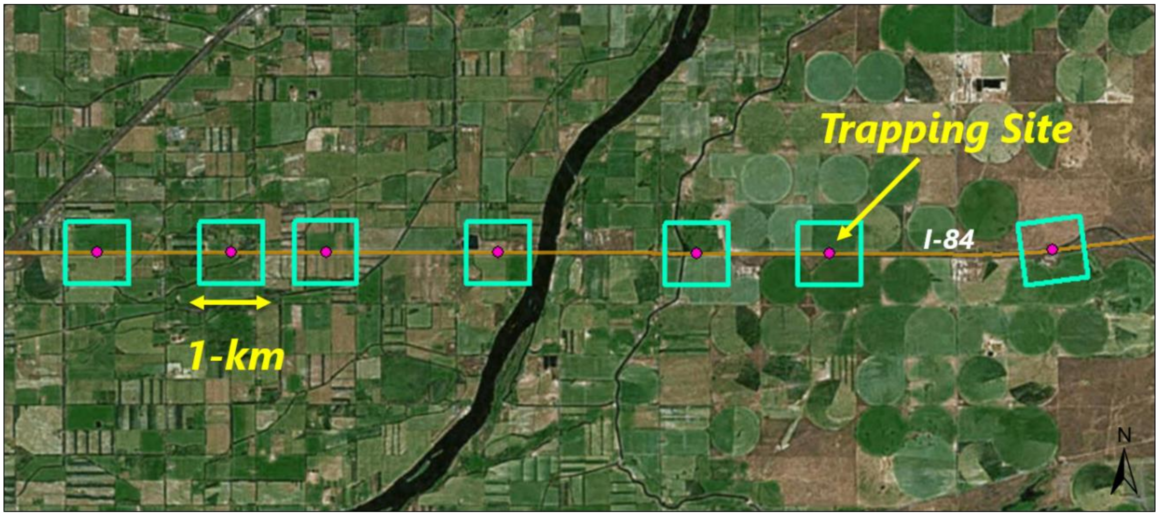


Figure 1.3 Figure illustrating how 1-km squares centered on 7 of the 120 trapping sites were configured. I also used 3- and 5-km squares centered on the 120 trapping sites to determine scale for each site variable I assessed in relation to barn owl mortality along I-84 (see Figure 1.4).

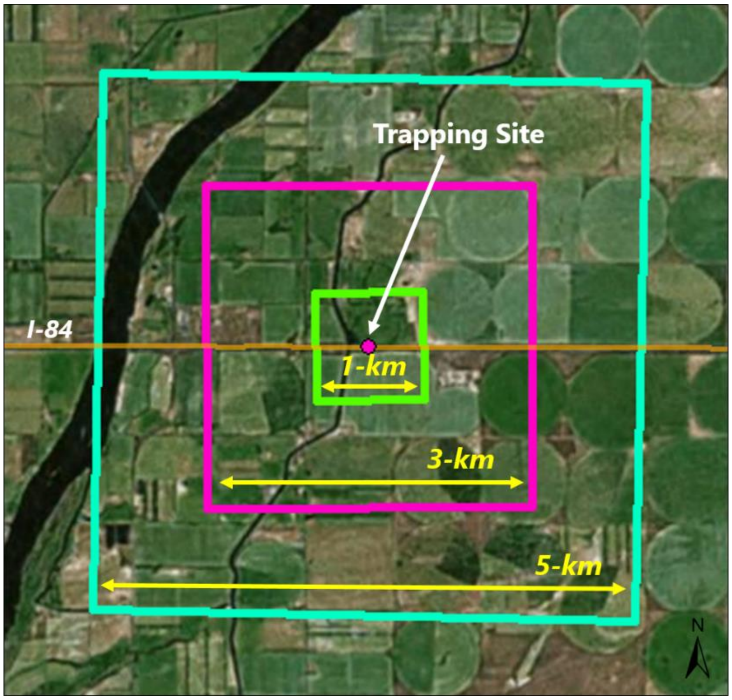


Figure 1.4 Squares (1-, 3-, and 5-km) centered on a trapping site.

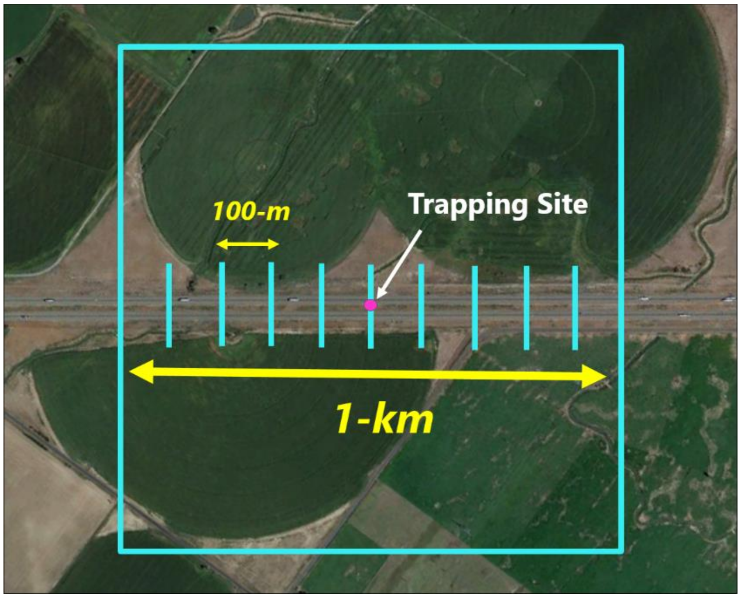


Figure 1.5 GIS image displaying 100-m increments within a 1-km square along I-84 used to calculate average and minimum distances.

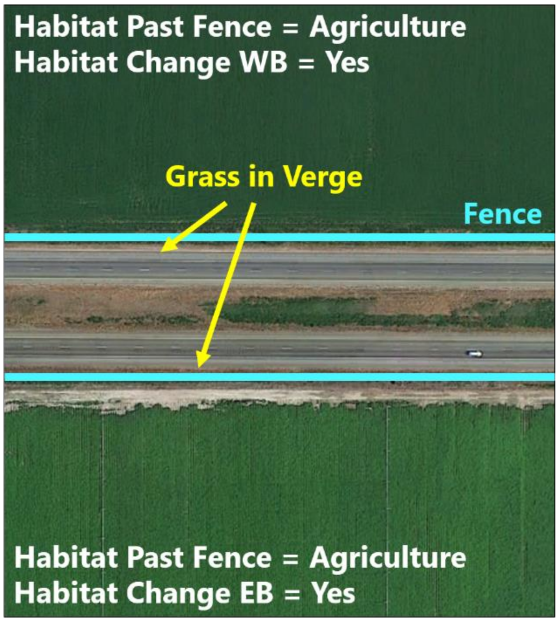


Figure 1.6 Measure of habitat change past the roadside verge fence along I-84.

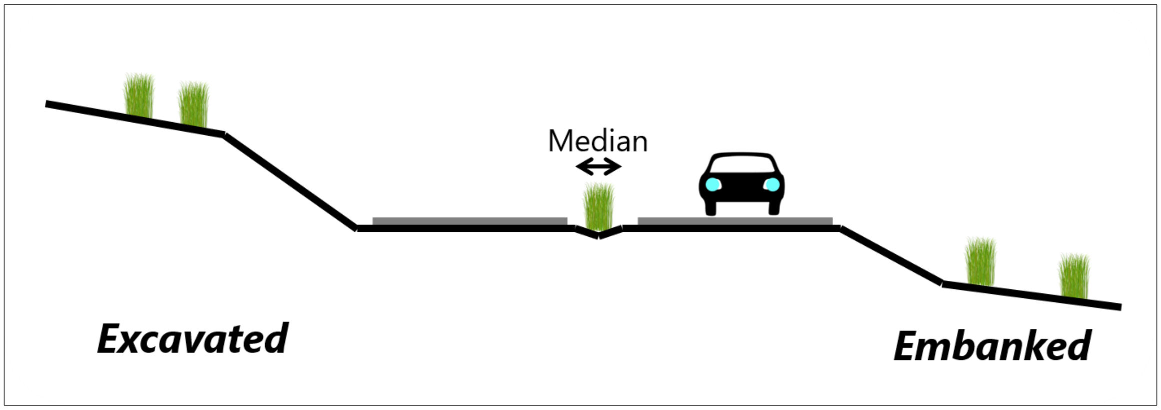


Figure 1.7 Schematic illustrating excavated and embanked portions of a roadway. The roadside verge rises above the road surface when excavated and sinks below the road surface when embanked.

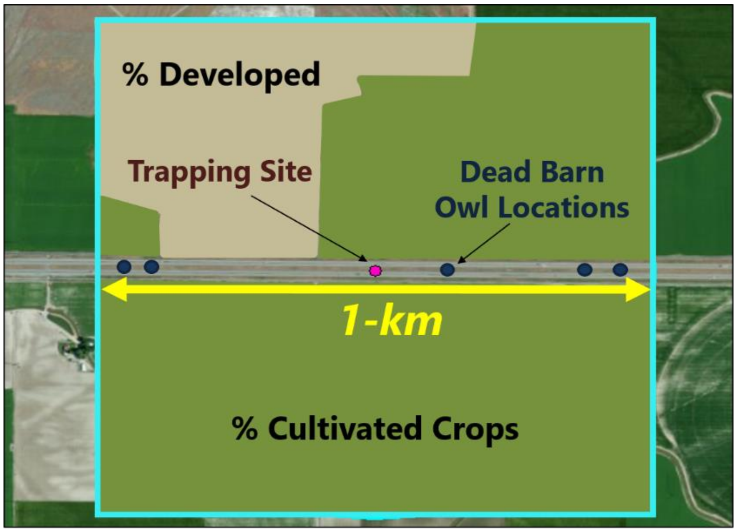


Figure 1.8 Characterization of land cover type for an I-84 segment with a 1-km square centered on a trapping site.

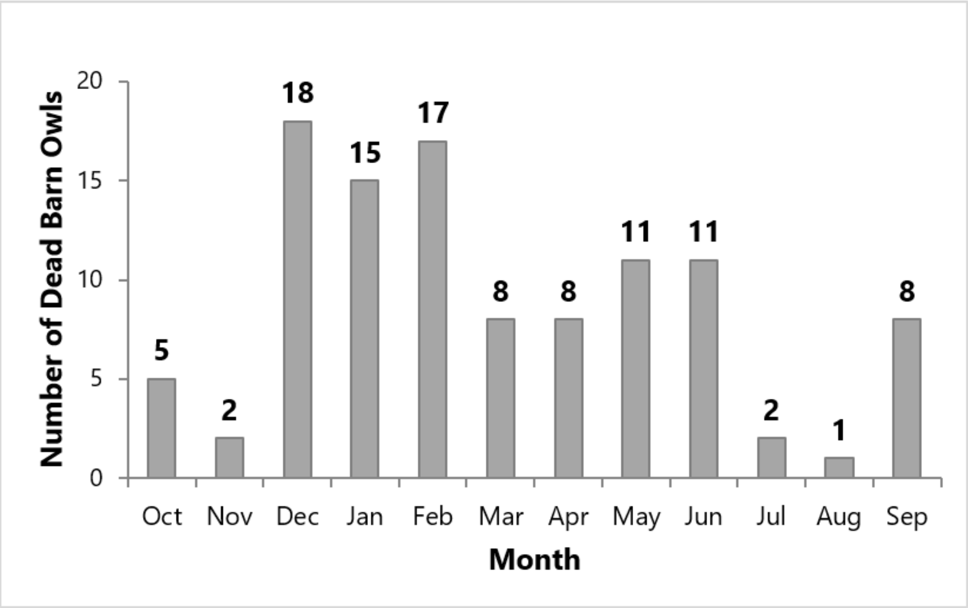


Figure 1.9 Number of dead barn owls per month during *standardized surveys* (October 2013 to September 2014).

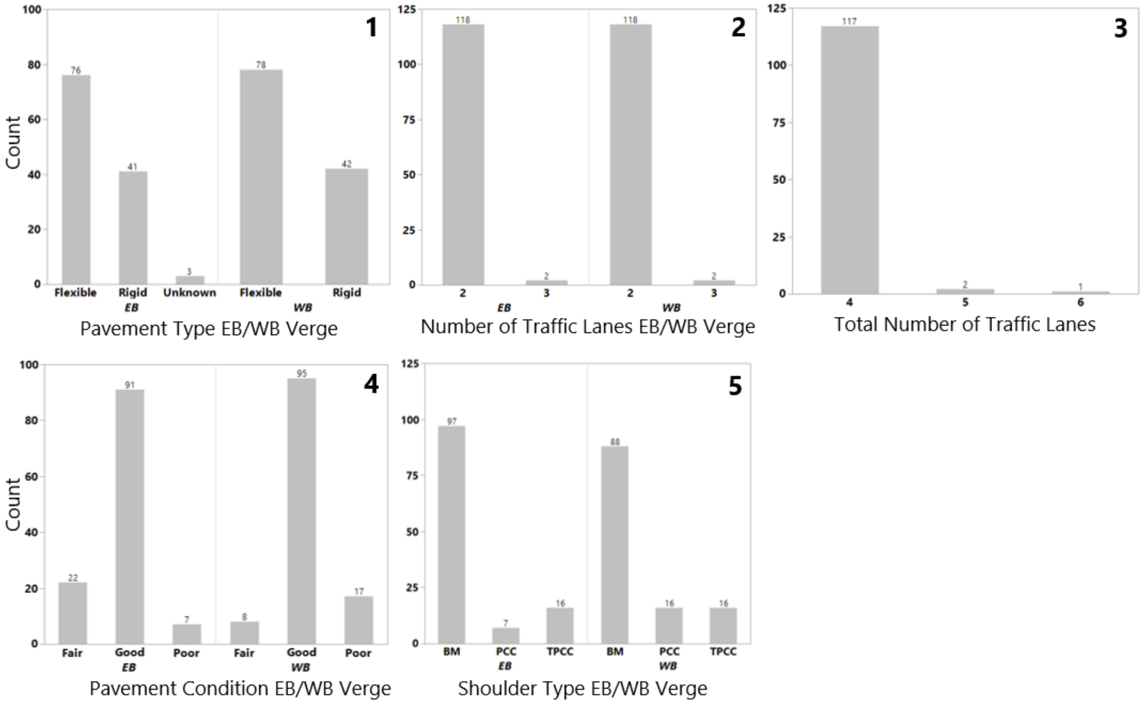


Figure 1.10 Frequency of pavement type (1), traffic lanes EB/WB (2), total traffic lanes (3), pavement condition (4), and shoulder type (5) at 120 trapping sites. Percentage of 120 sites are above bars. BM = surfaced with bituminous material, PCC = surfaced with PCC, and TPCC = surfaced with tied PCC.

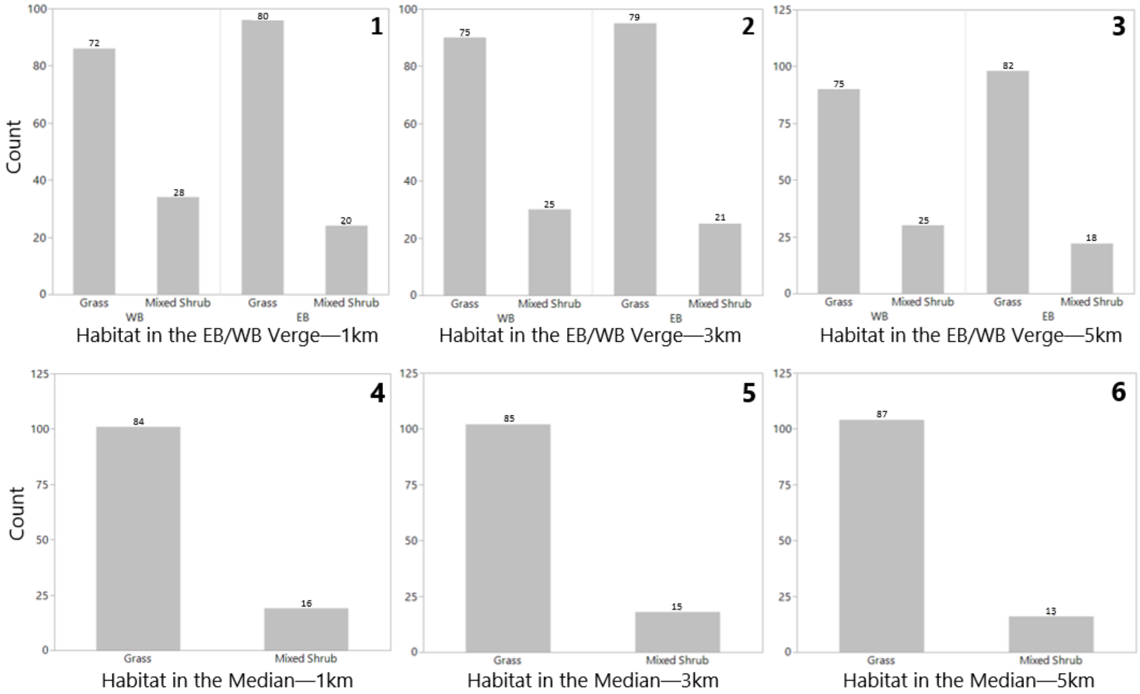


Figure 1.11 Frequency of plant cover type in the EB/WB verge at 1-, 3- , and 5-km scales (1-3), and frequency of plant cover type in the median at 1- , 3- , and 5-km scales (4-6) centered on 120 trapping sites. Percentages of 120 sites are above bars.

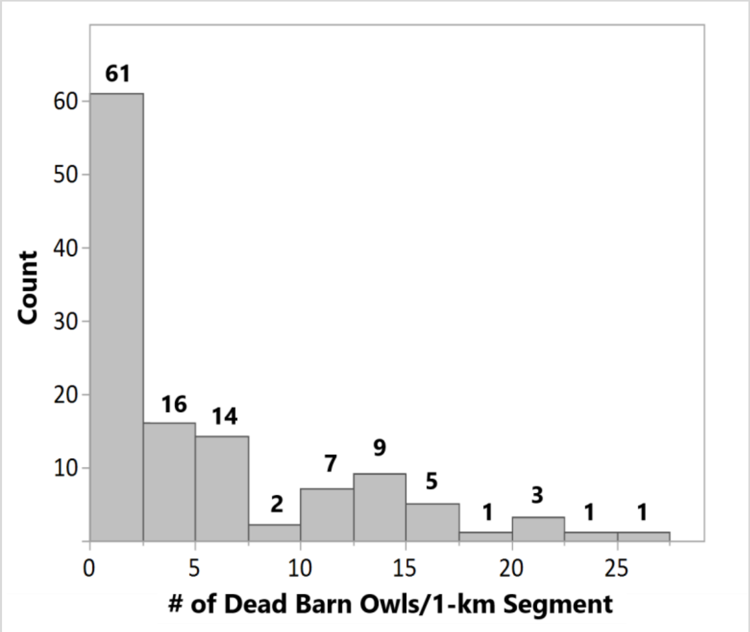


Figure 1.12 Frequency histogram of the number of dead barn owls/1-km segment (n = 120 segments) from combined survey periods (2004-2006 and 2013-2015).

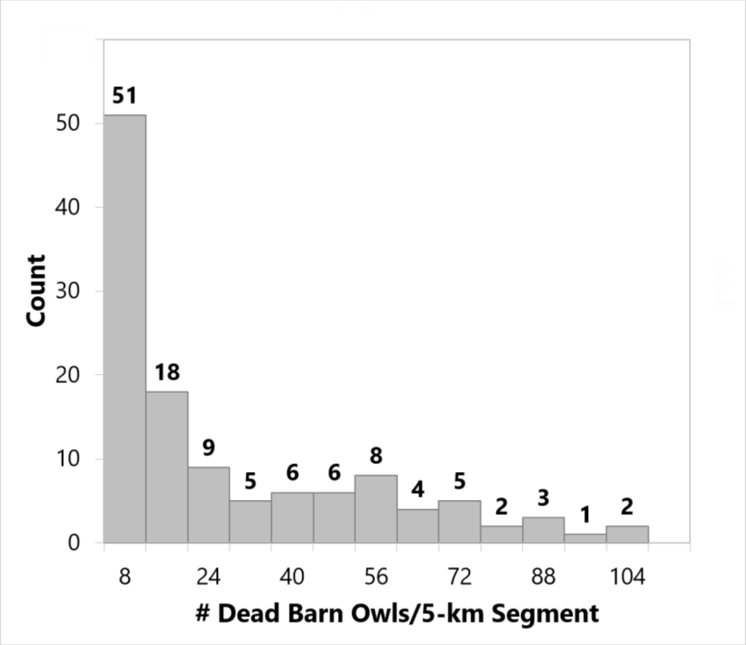


Figure 1.13 Frequency histogram of the number of dead barn owls/5-km segment (n = 120 segments) from combined survey periods (2004-2006 and 2013-2015).

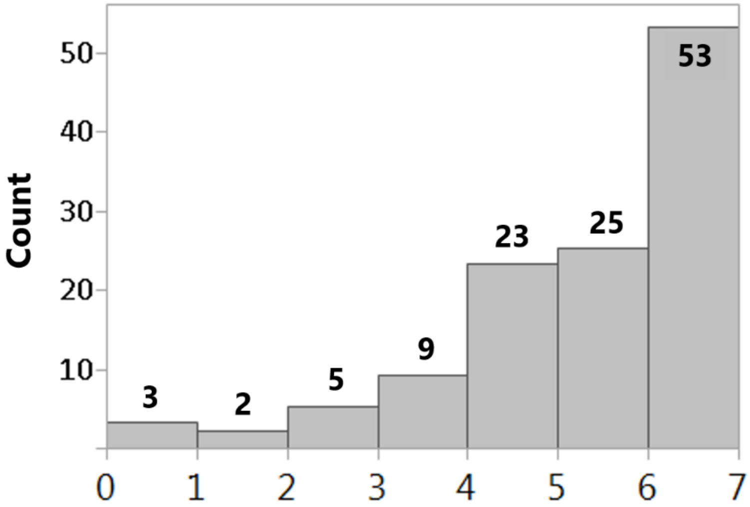


Figure 1.14 Frequency histogram of Small Mammal Abundance Index at 120 sites along I-84/86. Small Mammal Abundance Index averaged 4.8 ± 1.5 at the 120 trapping sites and ranged from 0-6.

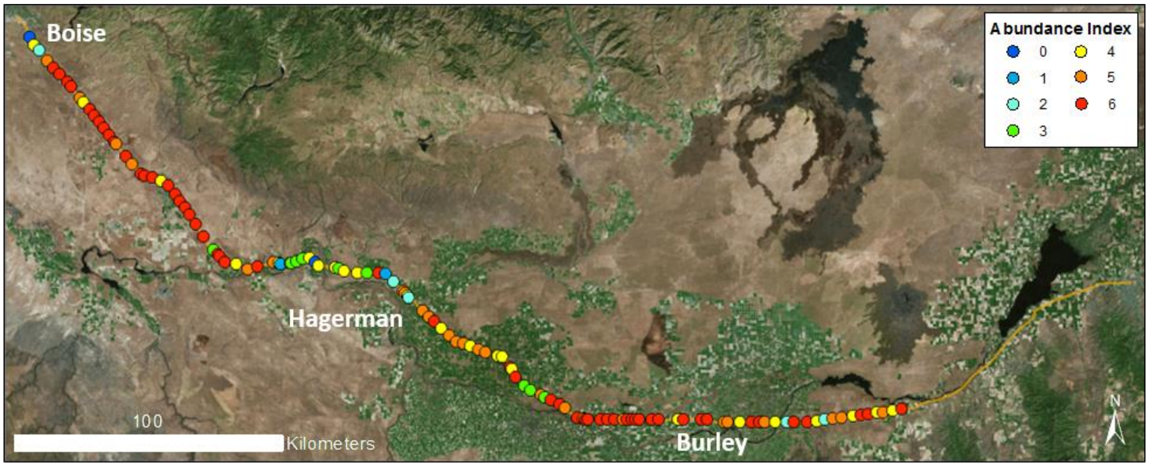


Figure 1.15 Small Mammal Abundance Index at 120 trapping sites along I-84/86. Species that contribute to the small mammal prey of barn owls were generally abundant at the 120 trapping sites.

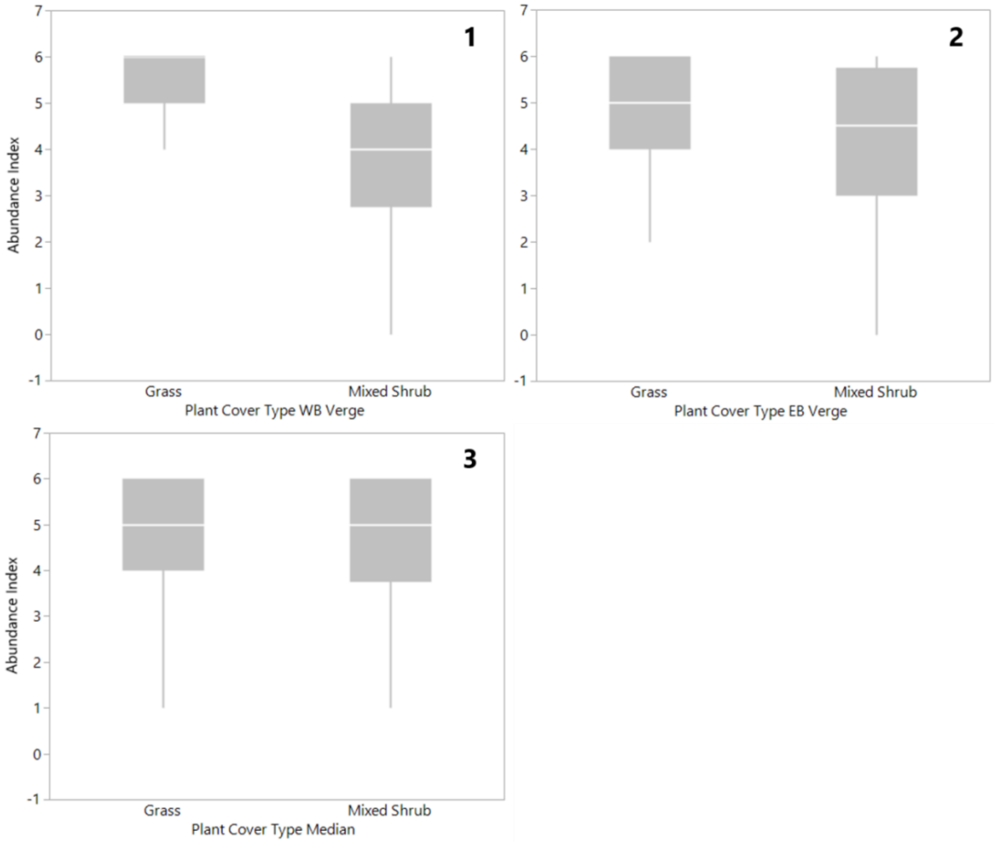


Figure 1.16 Box plots of Small Mammal Abundance Index in relation to plant cover type in the median, EB, and WB verges at 120 trapping sites along I-84/86. Plots display the mean, maximum and minimum values, and interquartile range. Average Small Mammal Abundance Index for (1) WB: Grass = 5.22 ± 1.06, Mixed Shrub = 3.68 ± 1.79; (2) EB: Grass = 4.96 ± 1.35, Mixed Shrub = 4.08 ± 1.77; (3) Median: Grass = 4.83 ± 1.47, Mixed Shrub = 4.5 ± 1.51. See Table 1.12 for results of statistical comparisons between plant cover types.

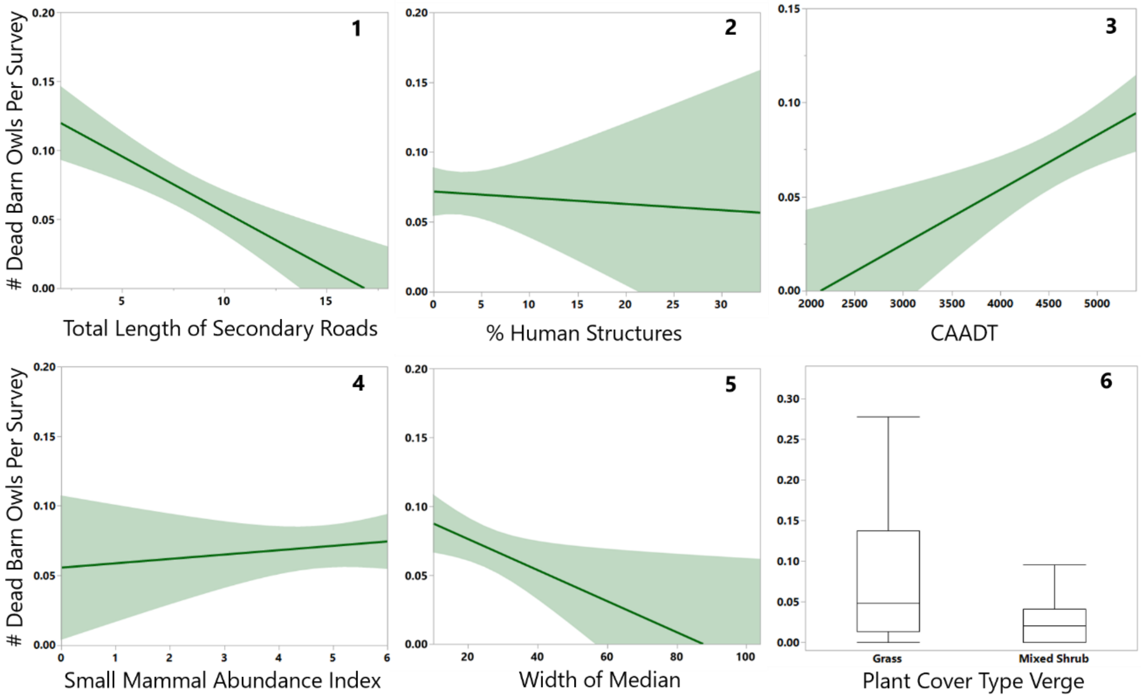


Figure 1.17 Model based relationships (± 95% CI) between numbers of road-killed barn owls per survey in 1-km segments along I-84/86 for six variables (panels 1-6) in top models.

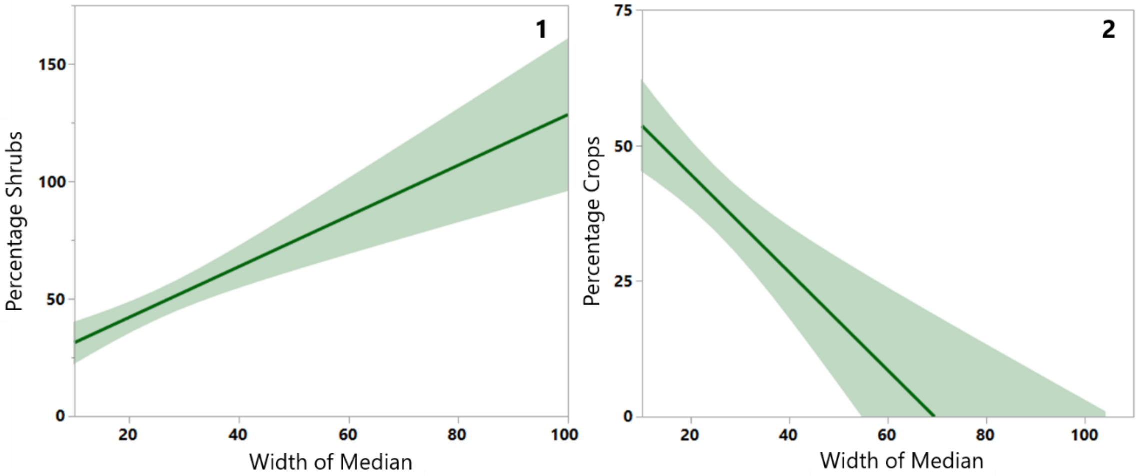


Figure 1.18 Relationship (± 95% CI) between width of the median and (1) percentage of shrubs and (2) percentage of crops along I-84/86. Width of median is positively associated with percentage shrubs ($p = 0.0008$, $r_s = 0.30$) and negatively associated with percentage crops ($p = 0.009$, $r_s = -0.24$).

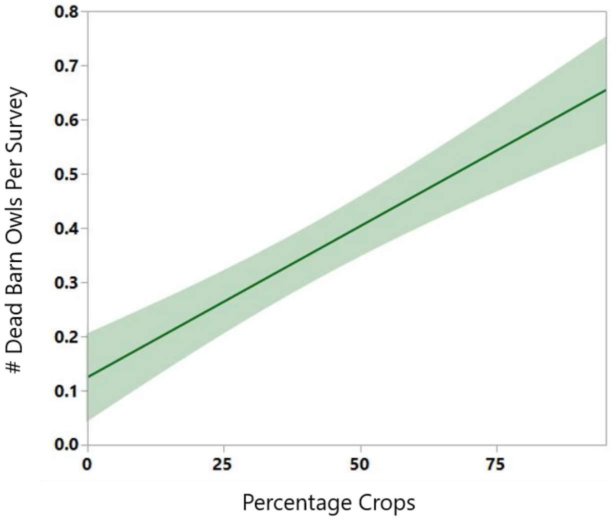


Figure 1.19 Model based relationship (± 95 % CI) between number of road-killed barn owls per survey in 5-km segments along I-84/86 and percentage crops, which was the single variable in the top model.

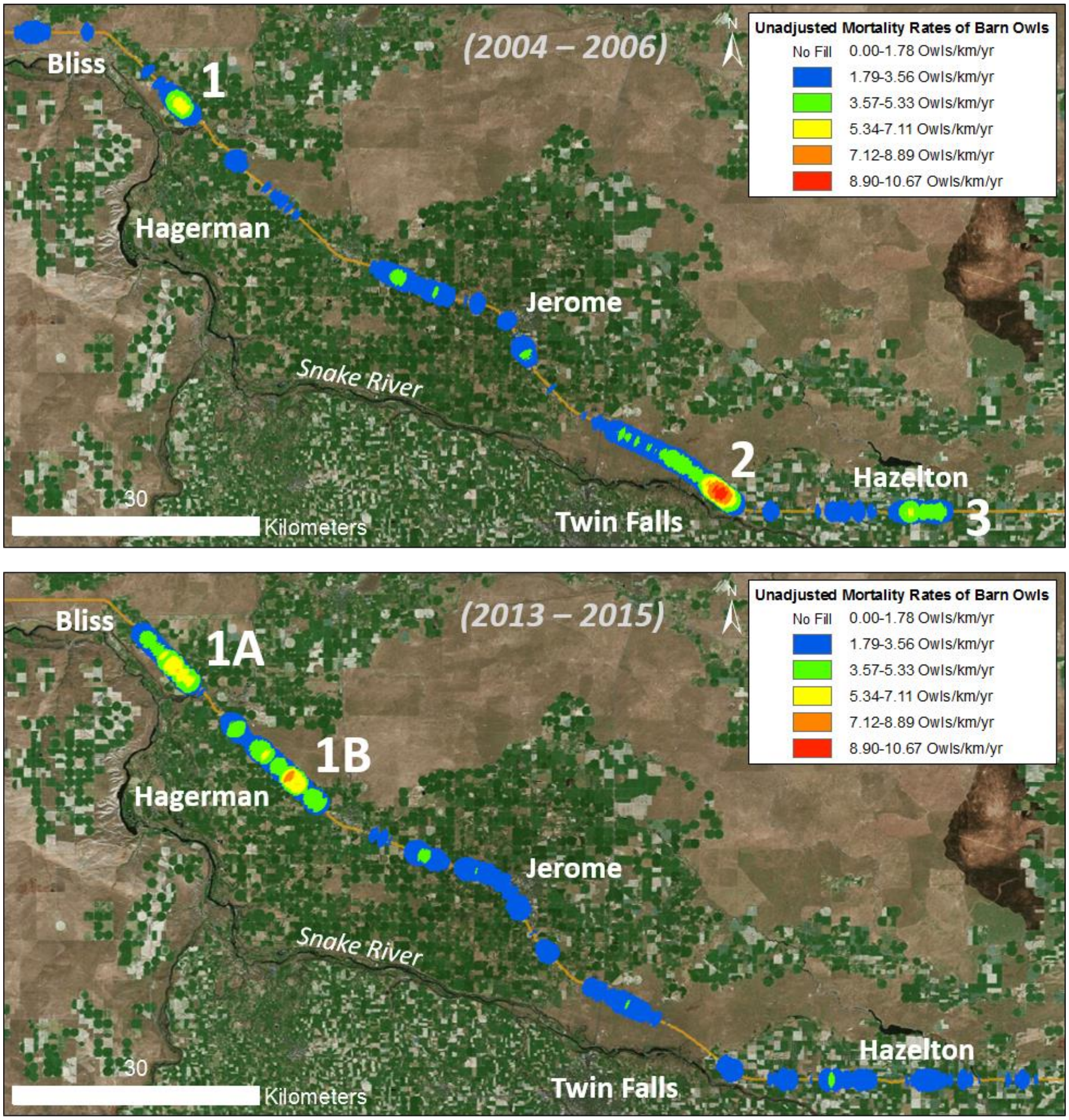


Figure 1.20 Point density estimates of barn owl road kills along I-84 between Bliss and Hazelton, Idaho along I-84. Top: Years 2004-2006; Bottom: Years 2013-2015.

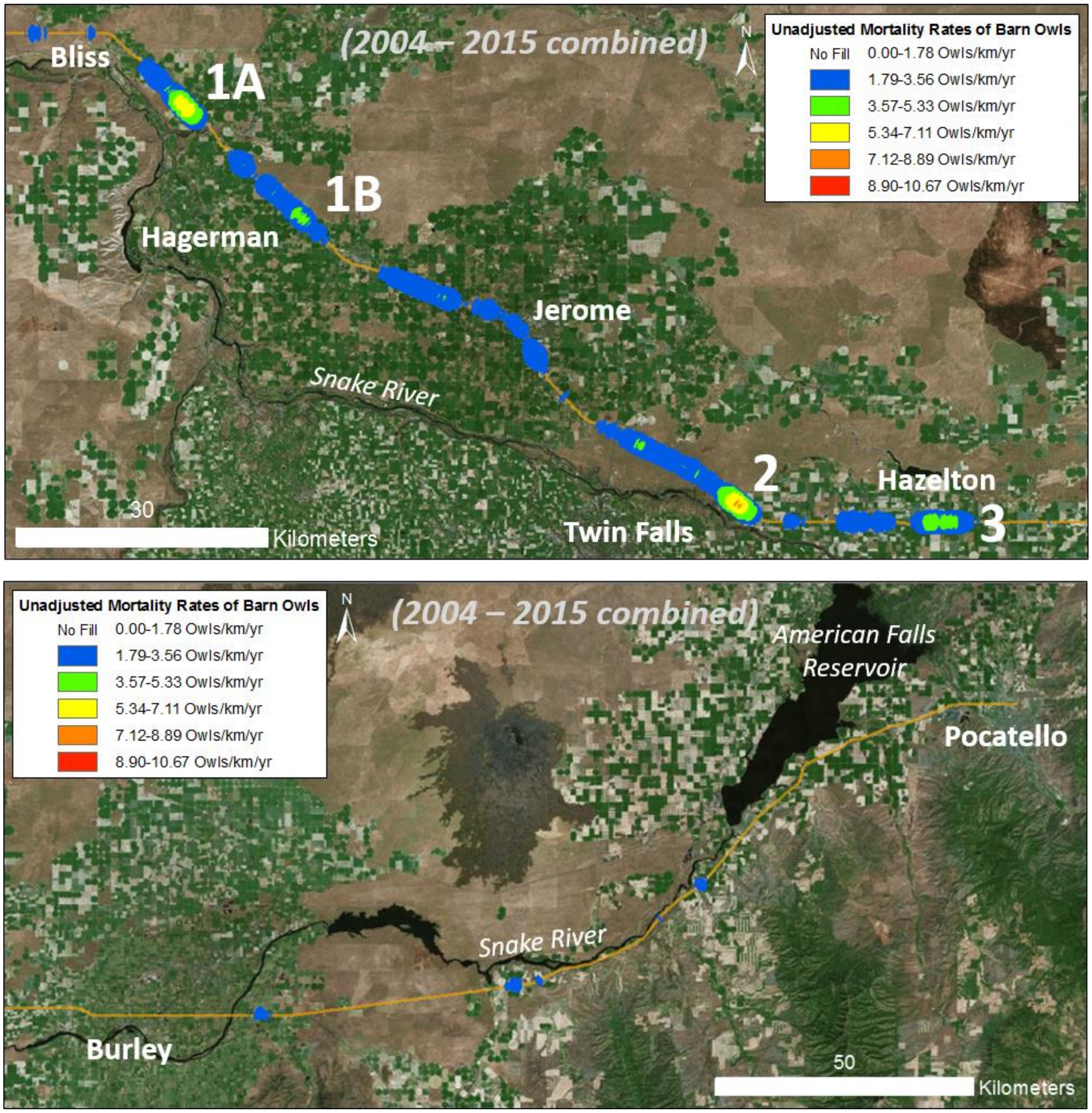


Figure 1.21 Point density estimates of barn owl road kills along I-84/86 using combined years (2004-2006 and 2013-2015) roadkill survey data.

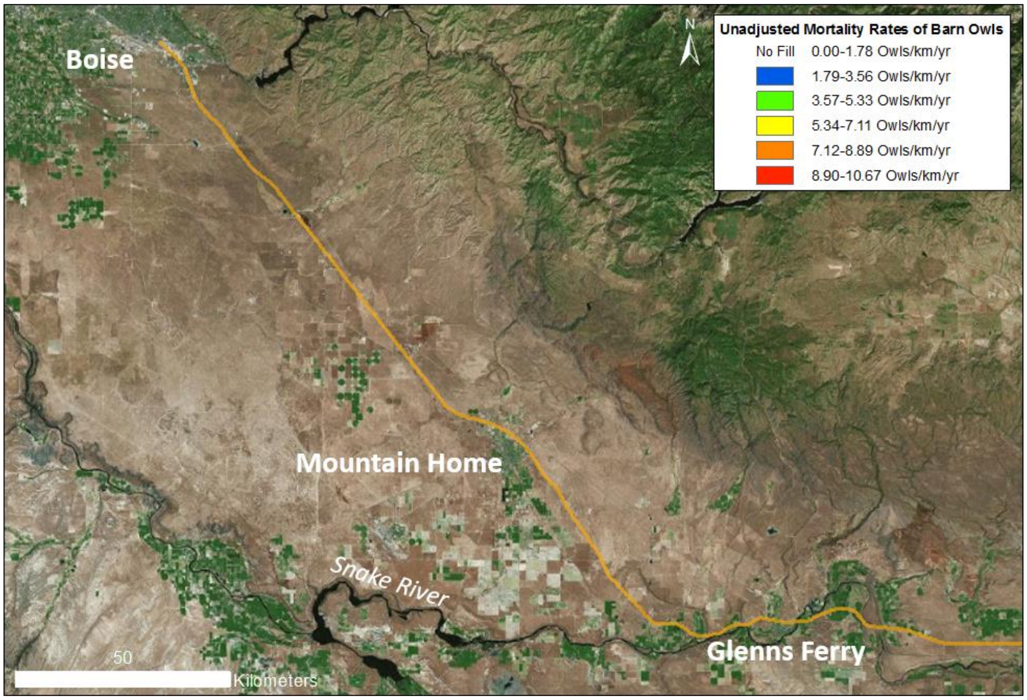


Figure 1.22 Point density estimates of barn owl road kills along I-84 between Boise and Glenns Ferry, Idaho. Note: this map is similar for 2004-2006, for 2013-2015, and for these time periods combined, so only one figure is shown. Owl mortality occurred between Boise and Glenns Ferry during these time periods but at low rates (0-1.78 owls/km/year), so no fill is shown.

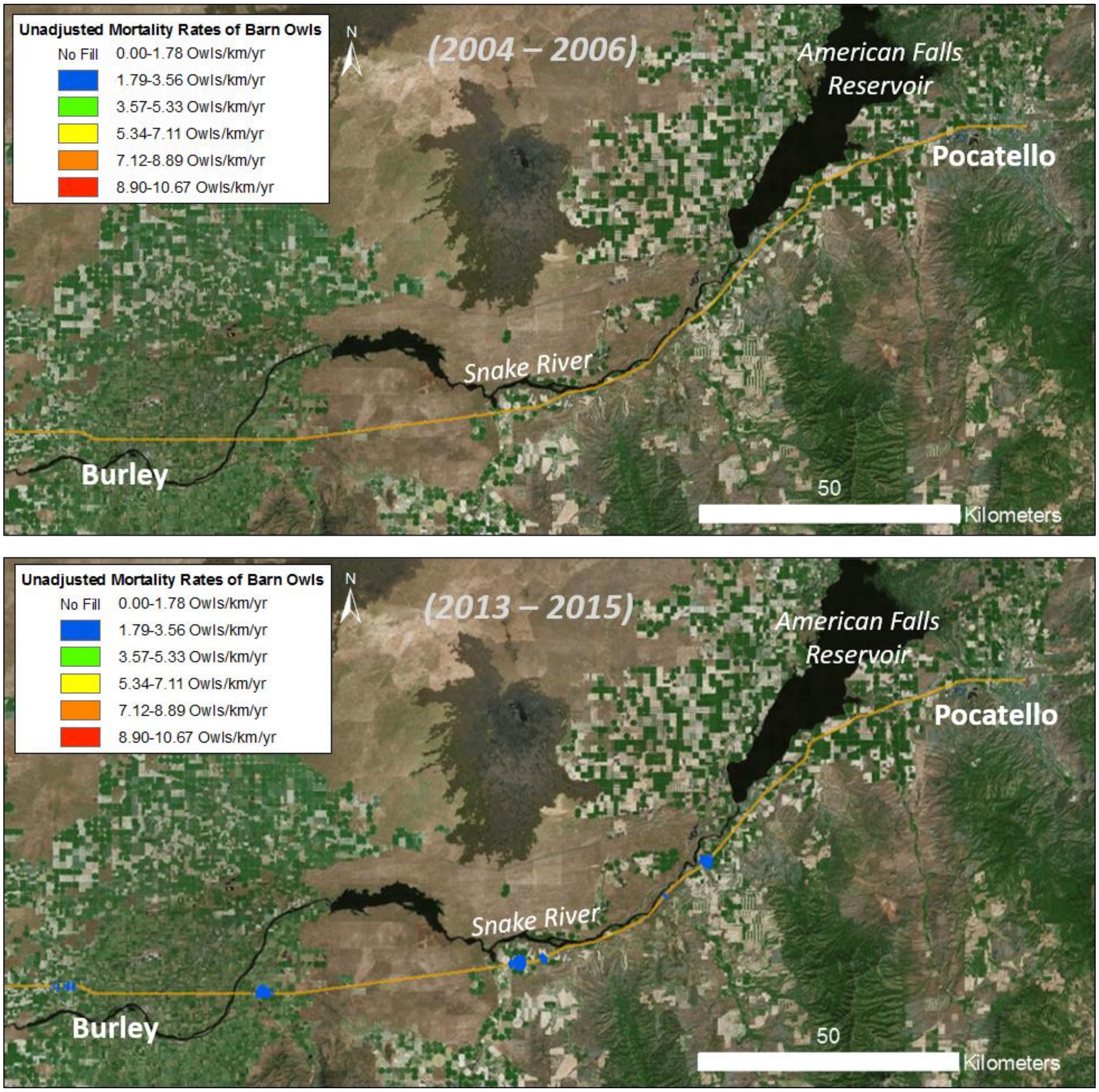


Figure 1.23 Point density estimates of barn owl road kills along I-84 between Burley and Pocatello, Idaho along I-84/86. Top: Years 2004-2006; Bottom: Years 2013-2015.

Figure 1.24 Land cover in 2004 (top) and 2013 (bottom) along I-84 near Twin Falls, Idaho. Figure displays region of hotspot #2 identified in the 2004-2006 survey period but which no longer appeared as a hotspot in the 2013-2015 survey period. Map Data: Google, USDA Farm Service Agency.

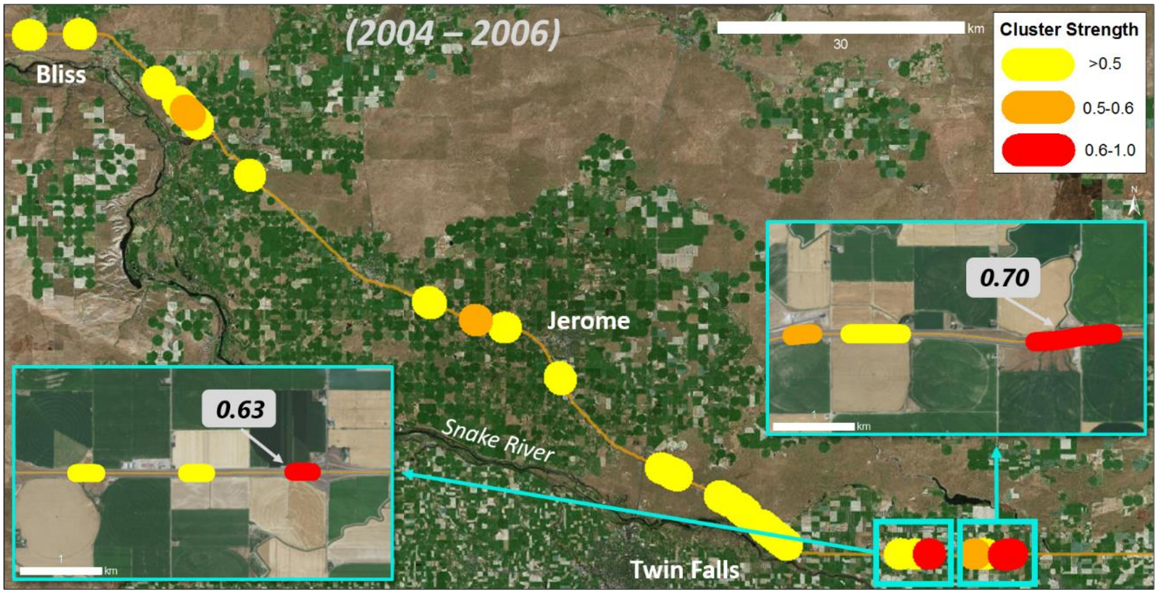


Figure 1.25 KDE+ analysis of barn owl mortality locations between Bliss and Hazelton, Idaho. Years: 2004-2006. Locations of the two clusters with the highest strengths (0.63 and 0.70) are magnified.

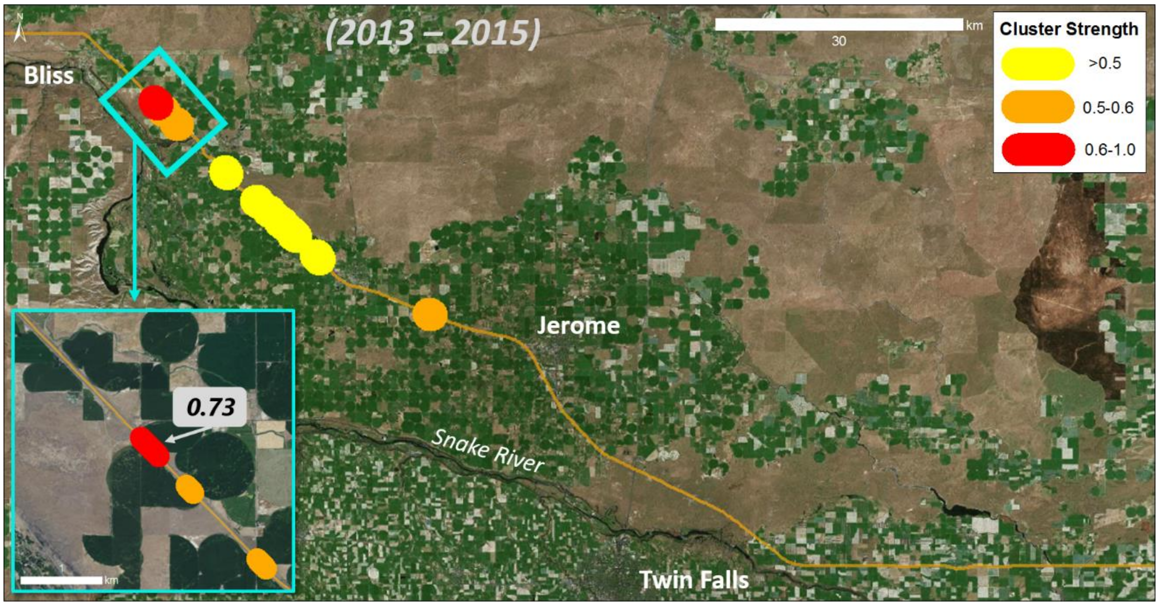


Figure 1.26 KDE+ analysis of barn owl mortality locations between Bliss and Hazelton, Idaho. Years: 2013-2015. Location of the cluster with the highest strength (0.73) is magnified.

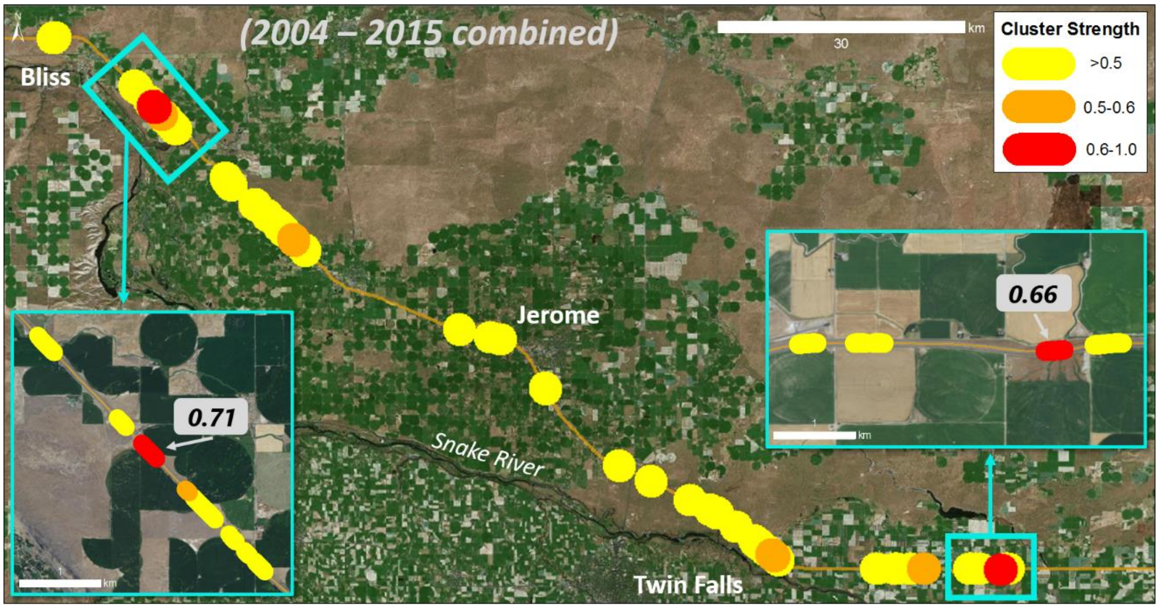


Figure 1.27 KDE+ analysis of barn owl mortality locations between Bliss and Hazelton, Idaho using combined years (2004-2006 and 2013-2015). Locations of the two clusters with the highest strengths (0.66 and 0.71) are magnified.

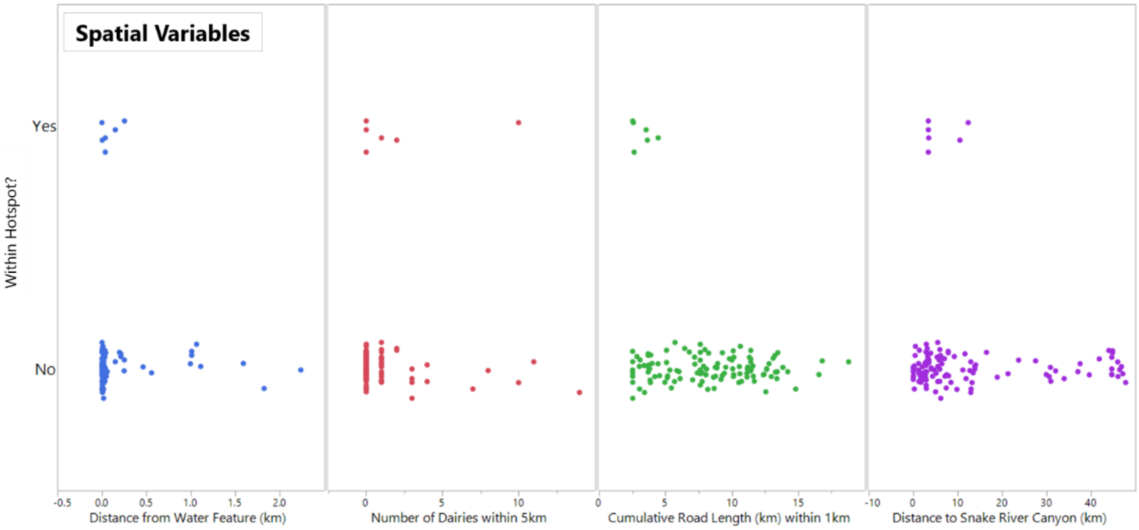


Figure 1.28 Scatterplot of *spatial* characteristics of 120 trapping sites along I-84 within (n = 6) and outside (n = 114) barn owl mortality hotspots. Hotspots were density map areas corresponding to mortality rates of 5.24-10.67 owls/km/year.

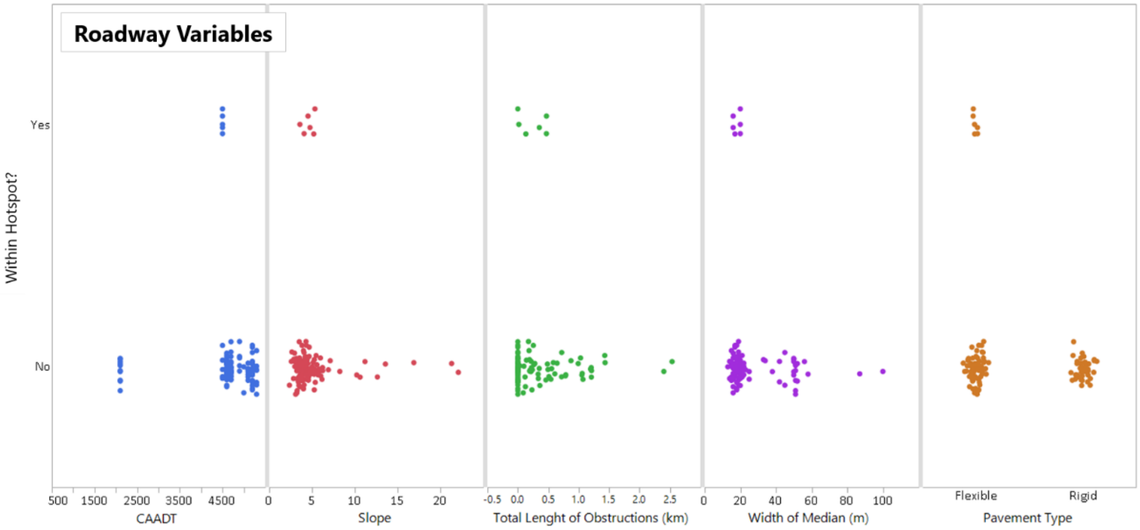


Figure 1.29 Scatterplot of *roadway* characteristics of 120 trapping sites along I-84 within (n = 6) and outside (n = 114) barn owl mortality hotspots. Hotspots were density map areas corresponding to mortality rates of 5.24-10.67 owls/km/year.

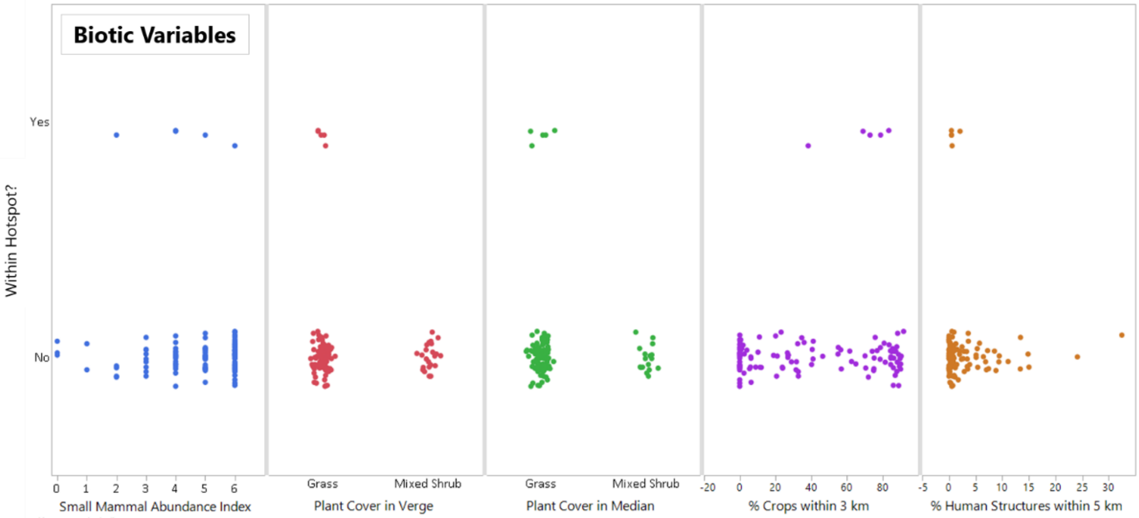


Figure 1.30 Scatterplot of *biotic* characteristics of 120 trapping sites along I-84 within (n = 6) and outside (n = 114) barn owl mortality hotspots. Hotspots were density map areas corresponding to mortality rates of 5.24-10.67 owls/km/year.

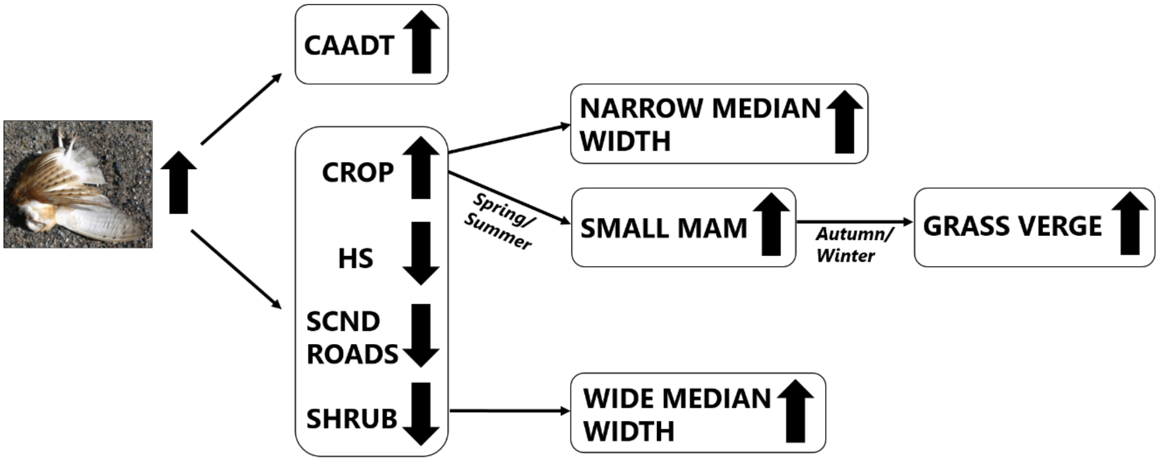


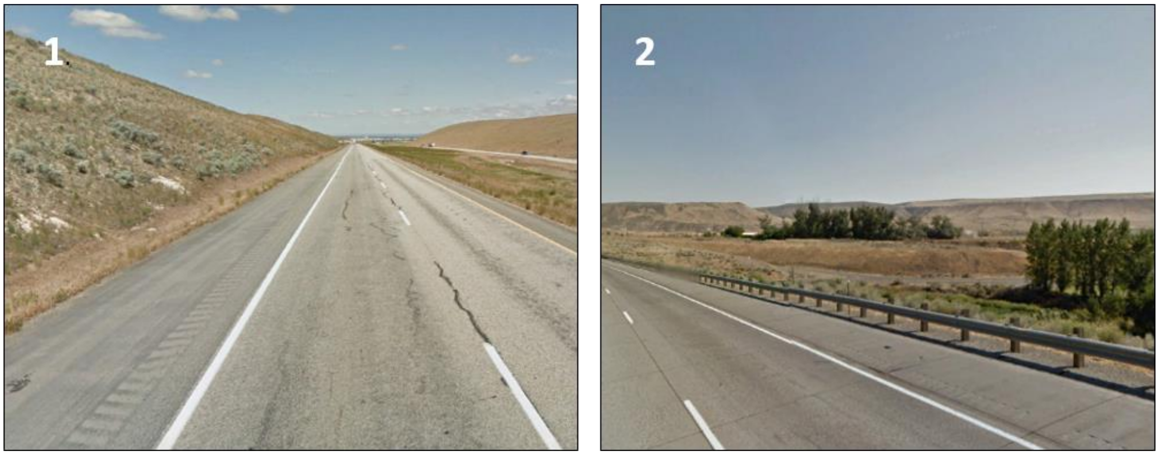
Figure 1.31 Summary of factors that influenced barn owl roadway mortality on I-84/86 in southern Idaho. Arrows indicate whether factor increases or decreases with increasing dead barn owls. Crop = % Crop, HS = % Human Structures, Roads = Cumulative Road Length, Shrub = % Shrub, Small Mam = Small Mammal Abundance Index. Crops likely provide good habitat for small mammals in spring/summer while grass verges provide good habitat in autumn/winter.

Pictures

Picture 1.1 Photo of dead barn owl illustrating direct roadway mortality along I-84 in southern Idaho.

Picture 1.2 Photo of road-killed barn owl along I-84 in southern Idaho (courtesy of Dr. Than Boves).

Picture 1.3 Photo of portion of I-84 roadside verge with grass plant cover type.



Picture 1.4 Photos of I-84 illustrating (1) excavated and (2) embanked portions of the roadway (Google Earth Imagery).

Picture 1.5 Photos of high mortality areas for barn owls, I-84 between Bliss and Tuttle, Idaho. Top: East view from eastbound shoulder; Bottom: West view from eastbound shoulder.

Picture 1.6 Photos of high mortality areas for barn owls, I-84 north of Kimberly, Idaho. Top: East view from eastbound shoulder; Bottom: North view from eastbound shoulder.

Picture 1.7 Photos of high mortality areas for barn owls, I-84 near Hazelton, Idaho. Top: East view from eastbound shoulder; Bottom: North view from eastbound lanes.

Picture 1.8 Photo of a low mortality area for barn owls, I-84 east of Glenns Ferry, Idaho. It is west view from westbound shoulder and features an excavated portion of road in which both sides of the road rise above the road surface. This area was also surrounded by shrubs (see top of hill adjacent to road).

Picture 1.9 Photo of a low mortality area for barn owls, I-84 west of Hammett, Idaho (west view from westbound shoulder). Although the landscape was relatively level with the road surface, it consisted primarily of shrubs.

APPENDIX

Methods: Small Mammal Abundance Survey

Methods: Small Mammal Abundance Survey

Study Area

I did the small mammal abundance surveys on the 289-km section of I-84 corridor between Boise and Burley, Idaho. I randomly selected (using ArcGIS) 120 trapping sites for small mammals and surveyed them between December 2013 and July 2014 (Figure A.1). I conducted small mammal abundance surveys using camera and track traps, which made it possible to collect small mammal occupancy data with fewer personnel and at lower costs (Mabee 1998, De Bondi et al. 2010). Previous research has supported both camera trapping (De Bondi et al. 2010, DeSa et al. 2012, Garrote et al. 2012, Manzo et al. 2012, McCallum 2012, Glen et al. 2013) and track trapping (Quy et al. 1993, Drennan et al. 1998, Mabee 1998, Glennon et al. 2002, Connors et al. 2005, Loggins et al. 2010) as acceptable methods for estimating abundance of wildlife species (small mammals specifically??). Thirty trail cameras (M-990i and M80 Moultrie Digital Game Cameras, motion triggered, infrared capable for night photography) were available for my study along with 120 track traps.

Track Traps

I constructed track traps based on modifications of Mabee (1998) using 10 cm PVC tubing flattened on the bottom so that openings on each side were 7.5 cm. I fitted each trap with a removable track plate (23 cm long x 7 cm wide) that had felt pads (7 x 5 cm) at each end which I inked with a mixture of lampblack and mineral oil. I also fitted the track plate with index paper (12.7 cm long x 7 cm wide), and I baited the track trap with rolled oats and peanut butter on a nightly basis by distributing the peanut butter mixture in the center of the roof of the trap.

As small mammals walked across the ink they left their tracks recorded on the piece of paper. I then used these tracks to identify species of small mammals (Picture A.1). A single print from a particular species counted as a unique detection. That is, if a track paper contained five prints from a deer mouse (*Peromyscus maniculatus*), for example, I counted it as one unique detection as I had no way to determine how many individuals left the prints. If there were prints from two species, I scored it as a unique detection for each. To collect footprints from known small mammals to aid in identification of tracks, I also conducted live-trapping with traditional Sherman live traps (7.62 x 7.62 x 25.4 cm) along I-84. After capture in a live trap, I temporarily transferred small mammals to a small plastic arena where they walked on ink pads and paper to leave tracks with which I developed a reference collection.

Camera Traps

I mounted cameras (M-990i and M80 Moultrie Digital Game Cameras, motion triggered, infrared capable for night photography) onto a 122-cm piece of rebar which I attached using a 12.7 x 14 cm piece of wood. I drilled two holes through the wood to loop a hose clamp through and then hold the wood to the rebar. The hose clamp allowed the camera/wood mount to move easily up and down for adjustments. Additionally, I sawed notches into either side of the wood so the camera strap was supported around the wood. I used track traps as bait stations at camera traps, but without the track plate (Picture A.2). I placed the camera 1.5 m in front of the bait station with the bait station at the center of focus. As with the track traps, I baited the camera traps nightly using a mixture of rolled oats and peanut butter.

The cameras captured images of small mammals present at the bait station onto digital SD cards, which I retrieved daily and downloaded upon return to the laboratory. Motion activated camera traps were set to take pictures when triggered and then delay for 30 seconds before taking additional pictures if triggered again. They often obtained multiple pictures of the same individual small mammal at a trap, but I counted them as the same individual. I considered images taken more than 15 minutes apart as new detections (Picture A.3) but this did not count in the index used.

Trapping Sites and Survey Protocol

I established camera and track trap sites similarly except for a different configuration of traps at each. A camera site consisted of two cameras with bait stations on the eastbound verge and two cameras on the westbound verge of the highway. Cameras generally were not useful in the median because of the large number of false triggers passing cars produced; cameras in the verges were angled away from the road surface so as to avoid this issue. I surveyed the median using track traps at each small mammal trapping site. A track trap site consisted of two track traps on the eastbound verge, two on the westbound verge, and two in the median (Figure A.2) with approximately 20 m between each trap.

I trapped each location for 3 consecutive nights. Cameras recorded continuously during the time period they were deployed and bait stations were re-baited every 1-2 days. I replaced track trap papers and re-baited the trap every 1-2 days during the winter trapping session, and replaced/re-baited the traps every day during the summer trapping session. I did not use cameras traps during the summer trapping session.

Abundance Index and Barn Owl Mortality

The small mammal surveys produced ~99,500 digital images of small rodents and tracks from which I obtained data on the proportion of traps (camera or track) that were occupied (i.e., picture evidence of small mammals or tracks). As both camera and track traps do not allow for individual recognition of small mammals, I could not use traditional capture-recapture methods to determine the relative abundance of small mammals (Drennon et al. 1998, Glennon et al. 2002). Instead, my survey produced occupancy data from which I derived a small mammal abundance index. I calculated this index by totaling the number of track traps containing a print of a particular species or the number of cameras that captured an image of a particular species, summed over the entire 3-night survey at a given trapping site (Drennon et al. 1998, Glennon et al. 2002). The index ranged from 0-6 as there were six traps at each site.

I determined the index described above for each small mammal trapping site. Because barn owls eat a wide variety of small mammal species, I considered any small mammal as potential prey so did not categorize species in development of the index. These indices were then included in the barn owl mortality model discussed in Chapter 1.

Camera and Track Trap Comparison Study

Given that I used a mixture of track traps and camera traps it was pertinent to evaluate how these methods compared. I conducted a comparison study at 56 traps (14 sites) during January 2014 in which a track plate was placed in the camera’s bait station essentially making it a simultaneous track and camera trap. Seven sites were re-visited on the second and third days while the other seven sites were visited every day. This produced 140 comparisons and made it possible to compare if cameras were picking up small mammals on the periphery of the image that were not going in the traps or, alternatively, if the small mammals were not triggering the camera, so they were leaving tracks but not being photographed. I used a McNemar test to determine if there was a significant association between track traps and camera traps.

Results

Camera and Track Trap Comparison Study

A McNemar test showed there was a significant association between track traps and camera traps with a X^2 value of 8 and a p-value of 0.004 (Table A.1). Additionally, there was a Cohen's kappa of 0.76 indicating congruence between the two methods. These results support the use of both camera and track traps as they detected small mammals equivalently.

Number of Small Mammals Detected

The track traps and camera traps recorded a combined 3,108 observations, from which I was able to identify six species of small mammals, all of which were rodents (Table A.2, Picture A.4). There were also 519 observations for which the species of small mammals that marked the track traps or were captured in camera trap photographs could not be identified. For both camera and track traps, deer mice were the most commonly recorded small mammal species (Table A.2).

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Tables

Table A.1 Contingency table comparing camera and track traps. Yes = small mammal detected, No = small mammal not detected.

		Track Trap	
		Yes	**No**
Camera Trap	**Yes**	86	13
	No	2	39

Table A.2 Species detected with track traps, camera traps, and combined track and camera data. 1,139 small mammals were detected with track traps and 1,969 were detected with camera traps.

TRACK TRAPS			
Small Mammal	**Scientific Name**	**Count**	**Percentage**
Deer mouse	*Peromyscus maniculatus*	925	81.21
Ground squirrel	*Urocitellus* spp.	10	0.88
Vole	*Microtus* spp.	5	0.44
Norway rat	*Rattus norvegicus*	1	0.09
Yellow-bellied marmot	*Marmota flaviventris*	1	0.09
Unknown	Unknown	197	17.30
	Total	**1139**	**100**
CAMERA TRAPS			
Mammal	**Scientific Name**	**Count**	**Percentage**
Deer mouse	*Peromyscus maniculatus*	1625	79.42
Rabbit	*Sylvilagus audubonii*	37	1.81
Cat	*Felis silvestris catus*	30	1.47
Norway rat	*Rattus norvegicus*	16	0.78
Ord's kangaroo rat	*Dipodomys ordii*	6	0.29
Red fox	*Vulpes*	1	0.05
Horse	*Equus caballus*	1	0.05
Cow	*Bos taurus*	1	0.05
Coyote	*Canis latrans*	1	0.05
Small bird	Unknown	6	0.29
Unknown small mammal	Unknown	322	15.74
	Total	**2046**	**100**
	Total Small Mammals	**1969**	
COMBINED TRACK AND CAMERA TRAPS			
Small Mammal	**Scientific Name**	**Count**	**Percentage**

Deer mouse	*Peromyscus maniculatus*	2550	82.07
Norway rat	*Rattus norvegicus*	17	0.55
Ground squirrel	*Urocitellus* spp.	10	0.32
Ord's kangaroo rat	*Dipodomys ordii*	6	0.19
Vole	*Microtus* spp.	5	0.16
Yellow-bellied marmot	*Marmota flaviventris*	1	0.003
Unknown	Unknown	519	16.70
	Total	**3108**	**100**

Figures

Figure A.1 Map of small mammal trapping sites (n = 120) along I-84 between Boise and Burley, Idaho.

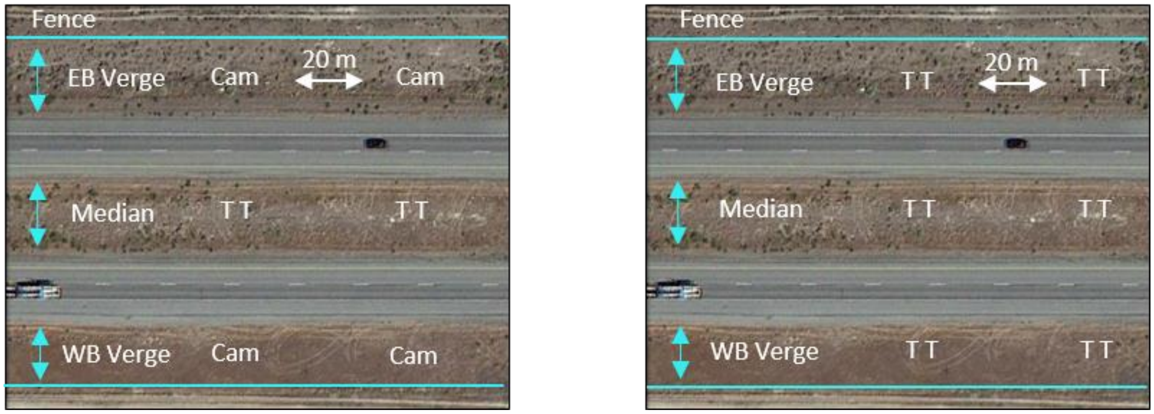
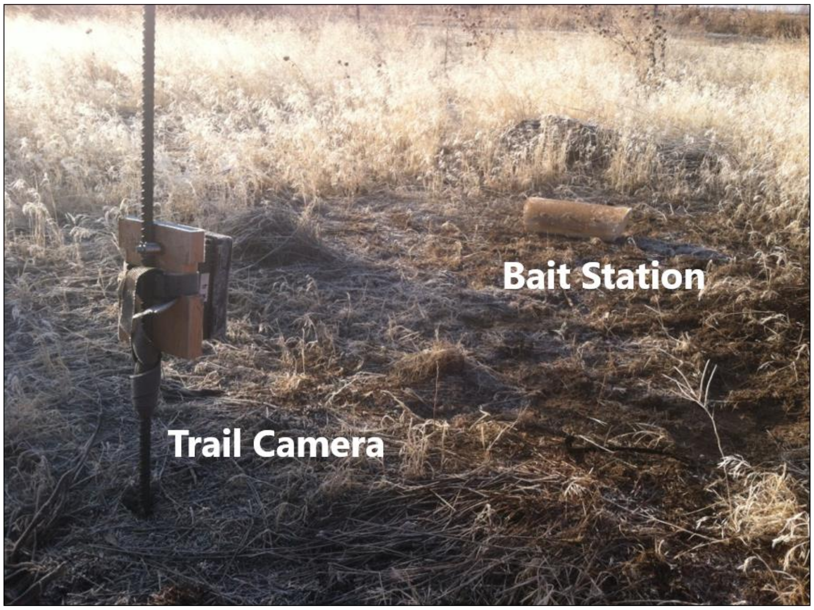


Figure A.2 Schematic illustrating camera trapping sites (left) and track trap sites (right). (TT) Track Trap; (Cam) Trail Camera; (EB Verge) Eastbound Verge; (WB Verge) Westbound Verge.

Pictures

Picture A.1 Track Trap (left) and Track Plate (right) showing small mammal footprints used to determine small mammal presence.



Picture A.2 Camera trap showing trail camera mounted on a stake and bait station.

Picture A.3 Photo from a camera trap showing presence of deer mice (*Peromyscus maniculatus*).

Picture A.4 Photos of deer mice (*Peromyscus maniculatus,* above) and a kangaroo rat (*Dipodomys ordii,* below) recorded at camera traps along I-84.