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Locations of deer–vehicle collisions are unrelated to traffic volume or posted speed limit

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Abstract: Consensus is lacking regarding the influence of vehicle speed and traffic volume on deer–vehicle collision (DVC) rates. Yet, annual average daily traffic flow (AADT) and posted speed limit (PSL) typically are used to measure these variables. To resolve this conflict, we studied the effects of traffic volume and vehicle speed on DVCs in Utah. Our results showed no relationship between AADT or PSL and DVC occurrence. There are at least 3 explanations for our results: (1) no causal relationship exists; (2) AADT and PSL, as measured, actually explain little of the variation; and (3) data quality problems exist. We discuss the likelihood for each explanation. We argue that even though traffic speed and volume have been used to predict DVC occurrence and may be useful explanatory variables, the metrics AADT and PSL are poor surrogate variables. Thus, uses of these variables to predict risk will likely provide unreliable results.

Key words: AADT, average annual daily traffic, connectivity, deer–vehicle collision, human–wildlife conflict, mitigation, *Odocoileus* spp., predictive models, posted speed limit, road ecology, road geometrics, scaling

Roads impact the natural environment (Christoffer 1991, Trombulak and Frissell 2000), as well as the health of ecosystems (Forman and Alexander 1998), species diversity (Fahrig et al. 1995), and animal abundance (Groot Bruinderink and Hazebroek 1996). Direct effects of these impacts are most evident through animal mortality on roads (Bissonette 2002). Scientists have attempted to explain the causes of deer–vehicle collisions (DVCs) by identifying environmental characteristics of roadways that correlate with areas of high concentrations of collisions (i.e., hot spots). Roadway characteristics usually are referred to collectively as road geometrics and include traffic volume and speed limit. Road characteristics have been reported to directly influence rates of animal–vehicle collisions (Forman and Alexander 1998, McShea et al. 2008, Ng et al. 2008). Often, posted speed limit (PSL) and annual average daily traffic flow (AADT) are used to measure these variables (Kassar 2005). There is, however, ambiguity in published results.

Depending on the species and area, some studies (e.g., Inbar and Mayer 1999, Hussain et al. 2007) have suggested that traffic volume is highly correlated with road mortality of animals, while other studies implicate speed as the major cause of animal–vehicle collisions (e.g., Gunther et al. 1998). Allen and McCullough (1976) found that when deer activity increased during dusk and dawn, traffic volume explained 85% of DVCs; however, they found a low correlation between seasonal traffic volume and DVCs. McCaffrey (1973) argued that local average daily traffic flow was too variable to allow for conclusions. Romin and Bissonette (1996) evaluated mule deer (*Odocoileus hemionus*) mortality on 3 highways and found that areas with more DVCs also had greater vehicle volume and speed. However, they emphasized the impact that traffic volume had on overall DVCs, while vehicle speeds were not as strongly or consistently correlated.

Rolley and Lehman (1992) did not find a positive correlation between traffic volume and DVCs. Rather, they implicated speed as a major cause of animal mortality, but suggested difficulties in determining the relative importance of speed in relation to other

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variables on road mortality of raccoons (*Procyon lotor*). Gunther et al. (1998) concluded that the actual speed of vehicles, rather than the PSL was better correlated with DVCs. Bashore et al. (1985) evaluated the PSL at DVC sites and found that it was negatively correlated with deer-kill probability. They suggested that PSL may have little relationship to actual vehicle speeds and that deer may cross less frequently at spots where vehicles move more quickly.

These variable results suggested to us that a closer examination was needed. Based on our review, we argue that attention to the characteristics of the explanatory variables used, as well as the scale resolution and extent with which they are collected, may be problematic.This can lead to different results and different interpretations of the data. To test this hypothesis, we studied the effects of PSL and AADT on DVCs on 4 state routes in Utah, USA.

Methods

Data set

Utah's diverse landscape consists of mountains, deserts, rangelands, agricultural lands, wetlands, and urban regions that are transected by ~9,500 km of 248 state highways and ~56,327 km of city and county roads. The Utah Department of Transportation (UDOT) maintains a database of information on DVCs from accident forms filled out by Utah Department of Public Safety law enforcement officers at the crash scene. DVCs are included in the database only if an animal was actually hit and if vehicle damage exceeded $1,000 or if personal injury resulted. Not counted as DVCs were crashes that occurred as a result of swerving to miss deer, those with >$1,000 in vehicle damage and without human injuries, and those not reported for other reasons, (e.g., no insurance). Because of these constraints, DVCs are underreported, and the number of DVCs reported here should be considered minimum estimates (Jahn 1959, Groot Bruinderink and Hazebroek 1996). Almost all animal–vehicle collisions involved mule deer; less than 1% involved moose (*Alces alces*) and elk (*Cervus elaphus*).

The collision data used for this paper came directly from the UDOT database containing information for each reported DVC occurring on all 248 state highways in Utah from 1992 to 2002. Each of the 24,210 DVC records included milepost, date, time, locality, alignment, PSL, and AADT for each route by year. We compiled data for each route into a spreadsheet, which we then imported into SAS 9.1.3 (SAS 2005). We identified segments of road for each of the 248 state routes that had >6.6 collisions per km over the 11-year period (1992–2002). For this paper, we identified and examined 4 routes (State Routes 40, 89, 189, and 91) that accounted for 6,198 or 25.6% of total collisions between 1992 and 2002.

Traffic volume data. In Utah, traffic volume data are recorded by sensors placed on sections of highway for a 48-hour period. The sensors record the day of the week, the month, and the functional class of the route, (e.g., interstate, collector, or other). Additionally, inductive loop-based counters throughout the state provide 365 days of data that are used to generate growth factors for each functional class. These data are then used to estimate changes in traffic volume and to adjust the 48-hour counts for the time of year that the count was taken. Sections are counted on a rotating 3-year cycle; for the other 2 years the AADT is based on a growth factor. To yield an AADT for a specific section of road, conversion growth factors for the day of the week and month are applied to the figure recorded within the 48-hour period. As development occurs, the actual location where data are collected may differ from year to year. Presumably, functional class conversion factors adjust the 48-hour reading to predict accurate AADT volumes. Counters are placed according to parameters that affect road design (e.g., number of lanes or intersections). Thus, AADT data are collected from road segments of unequal lengths among and within routes. Therefore, we used sections of road as the defining sections for our model. Using SAS Version 9.1.3, we extracted the data for each route from the larger dataset and created a traffic volume dataset (Figure 1, Step 1).

For each highway, we assigned a section number to each volume-defined segment (Figure 1, Step 2). We took the mean volume of all the years for each segment of road, and based on milepost, assigned it to its corresponding section (Figure 1, Step 3). We used the mean value for volume because it evenly weighs data

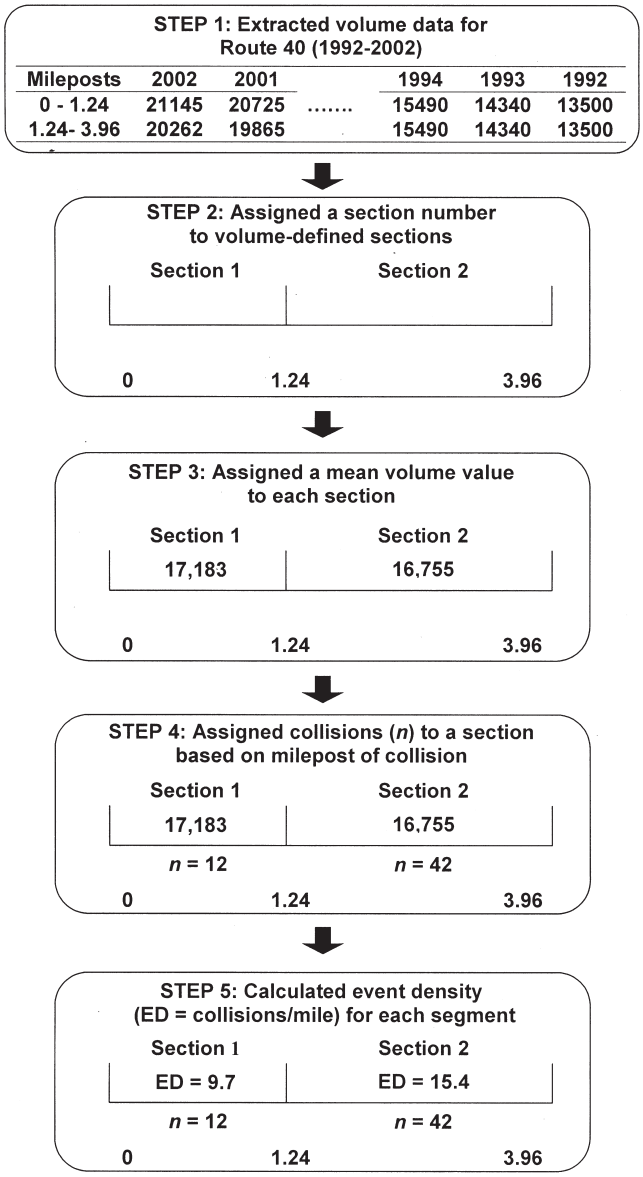

Figure 1. Flowchart showing an example of the process of creating the traffic volume data set for a portion of Route 40 from DVC data (1992–2002) in Utah.

from each of the 11 years and because the number of DVCs did not vary significantly from year to year (Bissonette and Kassar, unpublished data). Then, we assigned each DVC that occurred on that route into a section based on its milepost (Figure 1, Step 4). We then tallied the number of records in each section and calculated the event density (number of DVCs per segment mile) for each of these sections (Figure 1, Step 5). By standardizing the data (DVC density), we were able to determine if a correlation existed between the mean AADT and the number of DVCs across road segments of unequal lengths.

Posted speed limit (mph) data. In the original data set, the PSL, as well as an actual estimated vehicle speed, were assigned for each collision. We calculated the median PSL for collisions occurring in each section and compared it to the DVC density to test the relationship. The PSL data were variable; values reported ranged from 0 to 75 mph (127 km/hr). Because there are no road segments with a PSL of 0, we removed these DVCs from our analysis. Because we questioned the reliability of the data and because the PSL for a route did change frequently, we chose the median value to reflect the most common condition drivers would face and to prevent outliers from skewing the results. By doing this, we were purposely trying to maximize the possibility of a significant relationship; in other words, this was a best possible case scenario for these data.

Data analysis

We standardized the number of collisions by calculating DVC density (Figure 1, Step 5) because each of the volume-defined sections was of different length. Using SAS 9.1.3 to conduct multiple regression analyses, we compared mean SSDT and median PSL with DVC density to evaluate how AADT and PSL related to DVCs.

Results

In none of the 4 routes we analyzed was multiple regression significant between the explanatory variables (mean AADT and median PSL) and the number of DVCs (standardized DVC density) as the response variable (Table 1). Typical results of the analysis are given for Route 91 in Figure 2. We visually compared DVC density, mean AADT, and median PSL within road segments to examine how these variables were distributed across the route. It is

clear from Figure 2 that these variables changed differently along road segments. Additionally, results of correlations between median PSL and DVC density (Figure 3) and mean traffic volume and DVC density (Figure 4) showed no relationship.

Discussion

We expected to see definite patterns in terms of the factors impacting DVC hot spots, i.e., between AADT or PSL and DVCs. As the values of these variables increase, the expectation is that the number of DVCs should also increase. However, our results did not support these expectations despite using a database containing >24,000 DVC records. The variables PSL and AADT are inadequate descriptors of traffic volume and speed limit. The reasons may be related to problems with how the data are collected. PSL may change within a mile segment and on the same segments of road from year to year (Figure 5) because of how roads are designed (curves, blind spots, straight stretches) and because of construction and other development that changes road alignment over time. These factors make it difficult to use PSL

Table 1. Number of DVCs adjusted by road length (miles) and DVC density for 4 routes in Utah, 1992–2002.

Route number	Road length[1]	Number of DVCs	Accidents/mile	DVC density
40	175.2	1858	10.61	0.63–4698
89	417.8	3360	8.04	0.20–94.87
91	45.6	584	12.81	0.70 –33.33
189	29.2	396	13.55	1.27–37.78

[1] Standardized number of animal–vehicle collisions per mile for each traffic volume defined segment (see Methods for a fuller description).

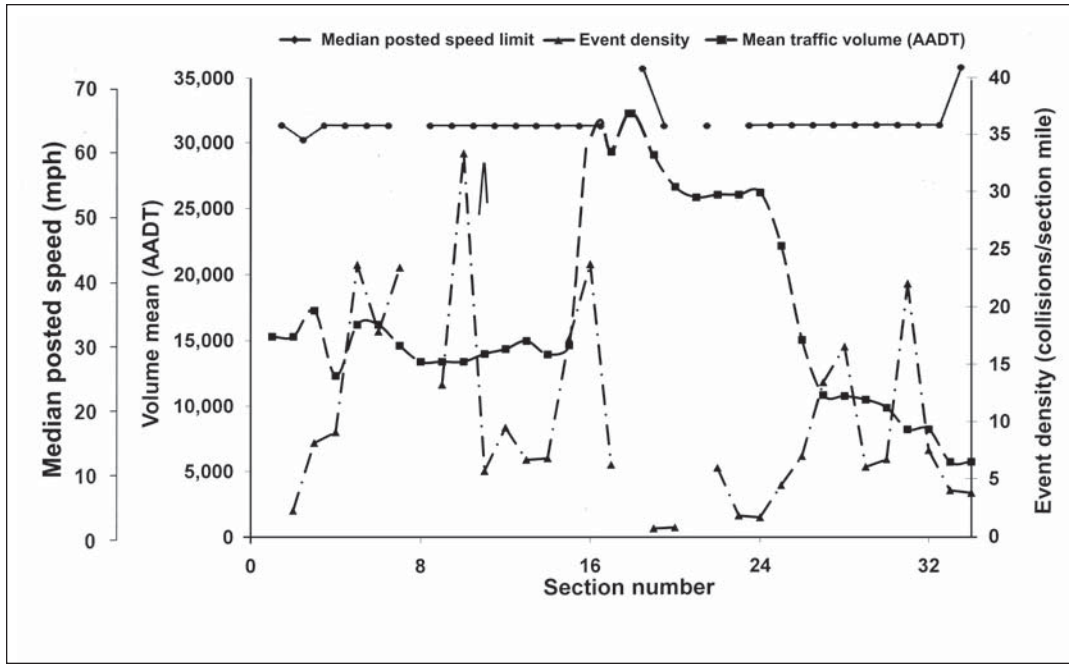

Figure 2. Traffic volume mean, median posted speed limit, and DVC density versus section number for Route 91, (Box Elder and Cache counties), Utah, 1992–2002 (event density equals DVCs/section length).

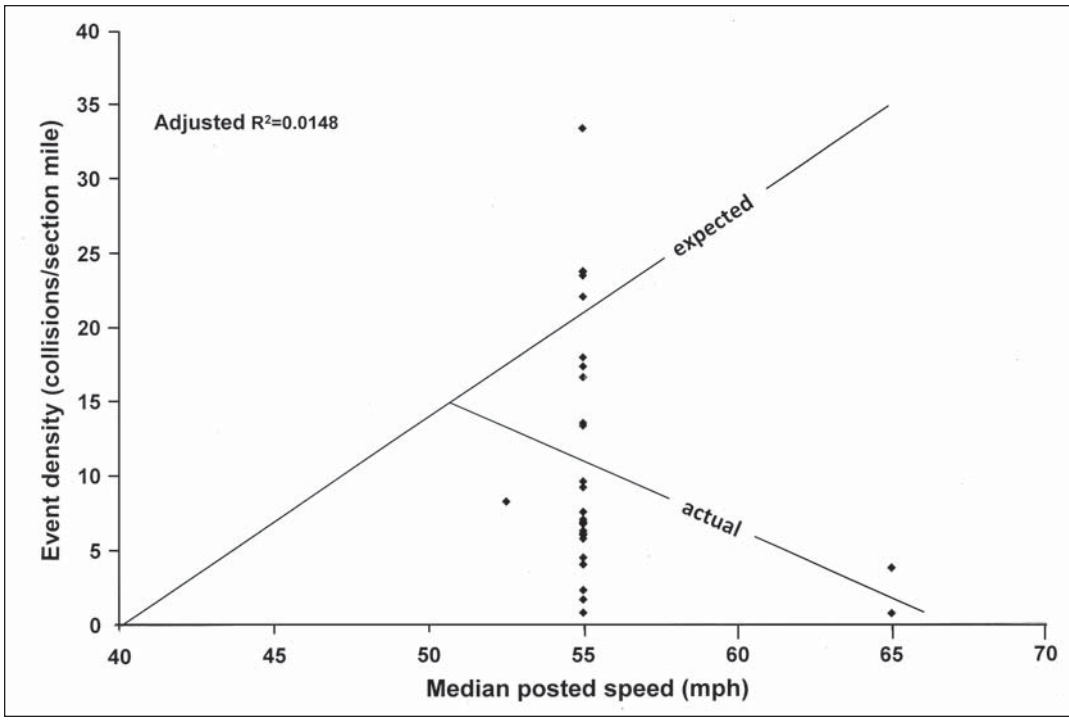

Figure 3. Deer–vehicle collision density (event density) versus median posted speed for Route 91 (expected relationship given as a 45° line).

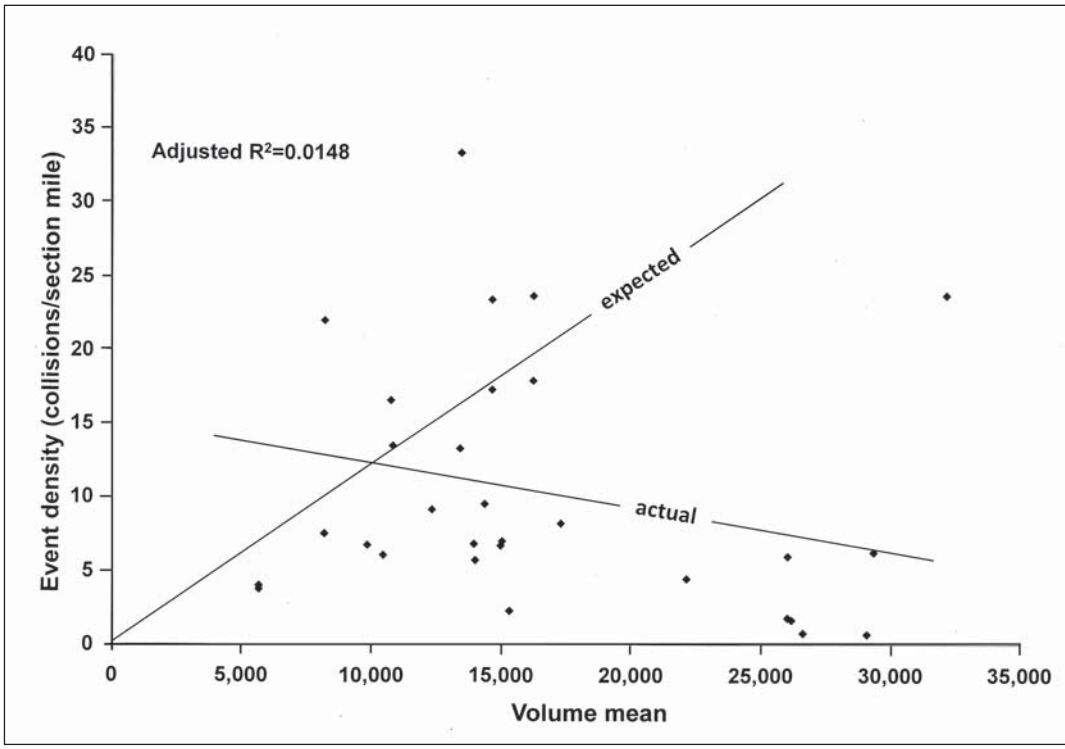

Figure 4. Deer–vehicle collision density (event density) versus traffic volume mean for Route 91 (expected relationship given as 45° line.

data to describe causal relationships within a hotspot or to make predictions regarding the effects of PSL on DVCs. That difficulty is reflected in the literature. For example, published reports are totally mixed. Allen and McCullough (1976), Case (1978), Gunther et al. (1998), and Romin and Bissonette (1996) have implicated speed as a major cause of collisions. Others (e.g., Jahn 1959 and Mansfield and Miller 1975) have found no significant relationship between DVCs and vehicle speed. Likewise, AADT data are collected in a manner that precludes their use to evaluate effects on DVCs. For example, UDOT collects traffic volume data on specific sections of road for 48 hours each year; these data are then adjusted based on certain road characteristics to determine a representative AADT. However, traffic volume is continually changing. Thus, drawing conclusions regarding its impact is problematic; again, the published reports reflect the problem. Allen and McCullough (1976), Arnold (1978), Brody and Pelton (1989), Fahrig et al. (1995), Inbar and Mayer (1999), Joyce and Mahoney (2001), Romin and Bissonette (1996), and van Langevelde and Jaarsma (2004) have reported that vehicle volume is highly correlated with road mortality. However, Carbaugh et al. 1975, Case 1978, Clevenger et al 2003, and Mansfield and Miller (1975) found no significant relationship. It appears that, depending on which descriptors are used, one obtains different results.

Actual vehicle speed may impact DVCs. Certainly, a vehicle moving at 120 km/hr does not have the same probability of being involved in a DVC as a vehicle travelling at 50 km/hr. However, other variables are important when considering DVCs. Whether roads are straight or curved influences line-of-sight for motorists, and even though winding roads are more likely to have lower speed limits, they are more likely to have higher DVCs. In mountainous country with high topographic relief, roads tend to be winding, and the presence of roadside vegetation in ravines and side canyons that provide cover is likely to increase the presence of deer near roads, increasing the exposure, and, hence, the likelihood of DVCs. Romin (1994), Lehnert (1996), and Grovenburg et al. (2008) reported that topographic and vegetative features in proximity to a road influenced habitat use and movement patterns of deer. Forman et al. (2003) reported that the proximity of habitat cover and movement corridors to the roadside greatly influenced DVC rates. Furthermore, the relationship between DVCs and traffic volume does not appear to be linear. Harrington and Conover (2007) reported that in northwestern Colorado and northeastern Utah, ungulate mortality on the road, as well as their presence on the right-of-way, was inversely related to traffic volume. Jaeger et al. (2005) and Alexander et al, (2005) have also suggested a barrier effect with increasing traffic volume. Alexander et al.

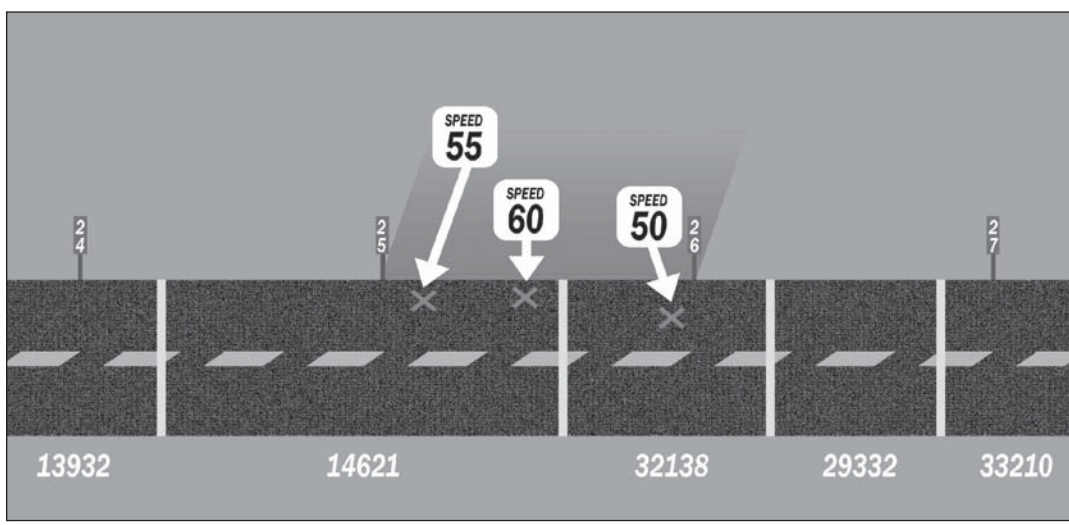

Figure 5. Scale issues involved with posted speed limit, mile post markers, and traffic volume variables. DVC databases are reported by mile marker in the U.S., making it difficult or impossible to correlate these variables with location of DVCs because they are measured at different extents and resolutions. Data from 1992–2002, Utah.

(2005) showed that traffic volume significantly reduced habitat permeability. Movement of ungulates across roads was impaired at traffic volumes between 500 and 5,000 vehicles per day.

DVC data: what data accuracy is needed?

How DVC data are used will influence not only the choice of explanatory variables, but also the degree of accuracy needed. Data on DVCs can be used for at least 2 different purposes: (1) hotspot analysis (Clevenger et al. 2003, Gunson and Clevenger 2003), and (2) predictive modeling (Finder et al. 1999, Elzohairy et al. 2004, van Langevelde and Jaarsma 2004). We suggest that if the objective is to define DVC hot spots for mitigation action, analyses that use existing data accurate to the mile marker produce acceptable results. However, developing a reliable and accurate predictive model of DVCs using explanatory environmental or roadway variables requires that (1) road-kill data are spatially explicit, (2) data regarding explanatory variables and road-kill are recorded at appropriate scale resolutions and extents and within temporal scale domains appropriate for comparison, (3) data are recorded accurately and completely, and (4) the model considers road geometrics and environmental variables. We argue that consideration of these factors in correlation with spatially explicit DVC data will allow for the development of a model with predictive possibilities. If research is used to inform the decisions made by state wildlife and highway agencies, then that research will be more useful if data collection and analysis reflects sensible adherence to spatial and temporal scale issues. Understanding the patterns and processes that lead to DVCs will allow us to develop practical preventative mitigation strategies.

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