3-2015

How Does Variation in Winter Weather Affect Deer-Vehicle Collision Rates

Daniel D. Olson
Utah State University

John A. Bissonette
Utah State University

Patricia C. Cramer
Utah State University

Patrick J. Jackson
Utah State University

Kevin D. Bunnell
Utah Division of Wildlife Resources

Daniel C. Coster
Utah State University

Recommended Citation

Olson, Daniel D.; Bissonette, John A.; Cramer, Patricia C.; Jackson, Patrick J.; Bunnell, Kevin D.; and Coster, Daniel C., "How Does Variation in Winter Weather Affect Deer-Vehicle Collision Rates" (2015). *Wildland Resources Faculty Publications.* Paper 1753.
http://digitalcommons.usu.edu/wild_facpub/1753

How does variation in winter weather affect deer—vehicle collision rates?

Author(s): Daniel D. Olson, John A. Bissonette, Patricia C. Cramer, Kevin D. Bunnell, Daniel C. Coster and Patrick J. Jackson

Source: Wildlife Biology, 21(2):80-87.

Published By: Nordic Board for Wildlife Research

DOI: http://dx.doi.org/10.2981/wlb.00043

URL: http://www.bioone.org/doi/full/10.2981/wlb.00043

Wildlife Biology 21: 80–87, 2015
doi: 10.2981/wlb.00043

Subject Editor: Anthony Clevenger. Editor-in-Chief: Ilse Storch. Accepted 3 December 2014

How does variation in winter weather affect deer–vehicle collision rates?

Daniel D. Olson, John A. Bissonette, Patricia C. Cramer, Kevin D. Bunnell, Daniel C. Coster and Patrick J. Jackson

D. D. Olson (dolson22@gmail.com), J. A. Bissonette, P. C. Cramer and P. J. Jackson, Dept of Wildland Resources, Utah State Univ., 5230 Old Main Hill, Logan, UT 84322, USA. – K. D. Bunnell, Utah Division of Wildlife Resources, 1470 N Airport Road, Cedar City, UT 84720, USA. – D. C. Coster, Dept of Mathematics and Statistics, Utah State Univ., 219 ANSC Logan, UT 84322, USA

Understanding how deer move in relationship to roads is critical, because deer are in vehicle collisions, and collisions cause vehicle damage, as well as human injuries and fatalities. In temperate climates, mule deer *Odocoileus hemionus* have distinct movement patterns that affect their spatial distribution in relationship to roads. In this paper, we analyzed deer movements during two consecutive winter seasons with vastly different conditions to determine how deer–vehicle collision rates responded. We predicted that deer–vehicle collision rates would be higher when precipitation and snow depth were higher. We used meteorological data from local weather stations to describe temperature, precipitation and snow depth. We monitored deer movements with global positioning system telemetry to document distance of deer to roads, elevation use and road crossing rates. We also documented changes in deer abundance and traffic volumes, which were potentially confounding variables. We found that precipitation decreased 50% and snow depth decreased 48% between winters. In response, deer used habitats that were 16% higher in elevation and that were 213% farther from roads with high traffic volumes. Consequently, crossing rates also decreased as much as 96% on roads with high traffic volumes. Reduced crossing rates were likely responsible for much of the 75% decrease in deer–vehicle collisions that occurred during the second winter. Abundance and traffic volume also can be important factors affecting deer–vehicle collisions rates. However, it is unlikely they were the major drivers of variation in deer–vehicle collisions during our study, because traffic volumes did not change between years and deer abundance only decreased 7%. Our data suggest a mechanism by which variation in winter conditions can contribute to differences in deer–vehicle collision rates between years. These findings have significant management implications for deer–vehicle collision mitigation.

Understanding how deer (Cervidae) move in relationship to roads is critical for wildlife and transportation management, because deer frequently are involved in vehicle collisions throughout much of the developed world (Groot Bruinderink and Hazebroek 1996, Conover 2001, Noro 2010). In the United States alone there are 1–2 million vehicle collisions with large animals annually, resulting in more than 8 billion dollars in economic costs; the majority of these accidents involve deer (Huijser et al. 2008). Deer–vehicle collisions (DVCs) not only can cause vehicle damage (Bissonette et al. 2008), but occasionally vehicle occupants are injured and in rare cases killed (Conover et al. 1995, Langley et al. 2006). Vehicle collisions are nearly always fatal for the deer (Allen and McCullough 1976).

Mule deer *Odocoileus hemionus* occur throughout much of western North America and are commonly involved in vehicle collisions (Reed 1981, Peterson and Messmer 2011, Bissonette and Rosa 2012). In temperate climates, most mule deer populations are migratory (Gruell and Papez 1963, Kucera 1992, Sawyer et al. 2009) and have distinct seasonal movement patterns that can affect their spatial distribution in relationship to roads (Stewart et al. 2010). For example in summer, deer typically use high elevation ranges with abundant resources (Boeker et al. 1972) that generally are farther from high-volume roads (Stewart et al. 2010). In early to late fall, mule deer generally move from high elevation summer ranges, largely in response to seasonally declining resource quality and snow accumulations that inhibit movement and decrease forage availability (Parker et al. 1984). Mule deer winter ranges are usually lower in elevation and occur on southern aspects that have lower snow accumulations (Gilbert et al. 1970, Garrott et al. 1987). Many roads are located on or near deer winter ranges, and deer may be closer to high-volume roads during winter in some landscapes (Reed 1981).

Variation in the seasonal and annual movement patterns of deer can produce marked changes in DVCs (Mysterud 2004, Sullivan 2011). A common seasonal pattern that has been observed for both mule deer and white-tailed deer *Odocoileus virginianus* is a rise in DVCs during spring and fall when deer transition between summer and winter ranges (Case 1978, Biggs et al. 2004, Grovenburg et al. 2008). Additionally, Reed and Woodard (1981) observed that DVC rates for mule deer appeared to vary annually in response to changes in winter conditions. Mule deer typically exhibit a high degree of fidelity to summer ranges (Thomas and Irby

1990, Kucera 1992), but the use of winter ranges may vary between years depending on winter conditions (Garrott et al. 1987, Brown 1992). For example, in southern Idaho during a mild winter only 52% of deer returned to the same winter range they used the previous year (Brown 1992). The use of different wintering areas between years may cause variation in the exposure of deer to high-volume roads.

Deer–vehicle collision rates are not only affected by movement patterns but also by deer abundance and traffic volumes on roads (Jahn 1959, Sullivan 2011, Rolandsen et al. 2011). Additionally, speed limit and road edge clearance have been implicated for cervids (Meisingset et al. 2014), while anthropogenic activity appears to influence elk *Cervus elaphus* activity patterns in North America but not mule deer (Barrueto et al. 2014). Collision rates have been shown to be associated with abundance for both red deer *Cervus elaphus* and mule deer (Romin and Bissonette 1996b, Mysterud 2004). For white-tailed deer, DeNicola and Williams (2008) observed a proportional decrease in DVCs by experimentally reducing deer abundance. DVC rates are also affected by traffic volume on roads (Romin and Bissonette 1996b, Ng et al. 2008). Collision models have indicated that traffic volume is one of the most important predictors of DVCs (Litvaitis and Tash 2008), and high DVC rates have been reported on roads with high traffic volumes (Romin and Bissonette 1996b). Alternatively, roads with low traffic volumes appear to have a limited effect on deer survival, even if they frequently cross these roads (Hansen et al. 2012). Consequently, it is important to consider the type of road and its traffic volume when examining effects on deer movements and collision rates (Neumann et al. 2012, Sawyer et al. 2013).

An understanding of how deer move in response to annual changes in weather is key to understanding variation in DVC rates in temperate climates (Rolandsen et al. 2011). In this paper, we analyzed mule deer movements during two consecutive winters with vastly different conditions to determine what effect weather had on DVC rates. We predicted that DVC rates would rise when precipitation and snow depth increased, because deep snow restricts deer movements to low elevation habitats that may increase exposure to high volume roads. We monitored deer movements to document road crossing rates, distance of deer to roads and elevation use during both winters. We used meteorological data to describe temperature, precipitation and snow depth in the study area. We also documented changes in deer abundance and traffic volumes, which were potentially confounding variables.

Methods

Study area

The study area (8278 km^2) was located on the western edge of the Rocky Mountains in central Utah (Fig. 1). Topography in this area was mountainous and highly variable (1463–3415 m). The climate was temperate; typical summer temperatures were >22°C and winter temperatures were <0°C (UCCW 2013). Precipitation occurred during all months of the year, but during most years, peaks in precipitation occurred during spring and fall. Total precipitation (203–406 mm) was variable between years (UCCW 2009, 2013). The majority of the study area consisted of the Wasatch Mountains ecoregion, but its eastern edge encompassed a small portion of the Colorado Plateau (Griffith and Omernik 2011). A variety of land cover types (>40) existed within the study area, but aspen *Populus tremuloidies*, Gambel oak *Quercus gambelii* and sagebrush *Artemisia* spp. were relatively common (Lowry et al. 2005). Mule deer, elk and a limited number of moose *Alces alces* occurred within the study area (Bernales et al. 2011).

Roads were common throughout the rural study area (Fig. 1), but most had low (<500 vehicles day^{-1}) traffic volumes (UDOT 2012). However, there were a few roads with higher traffic volumes. For example US 6, a major east–west route in Utah, bisected the center of the study area (Fig. 1). Traffic volumes on US 6 within the study area were ~9000 vehicles day^{-1} and speed limits varied between 72–105 km h^{-1} (UDOT 2012). In 2005, data showed that US 6 had the sixth highest number of DVCs in the state (Kassar and Bissonette 2005). To improve safety for motorists and deer, four wildlife crossing structures and 26 km of intermittent, exclusionary fencing (2.4 m high) were installed in 2008–2009 on US 6 within the study area. While most mitigation was in place prior to this study, one wildlife crossing structure (MP 204) and ~6 km of wildlife fencing were installed in 2011 during the study. Prior to installation, 6–7% of deer carcasses reported during winter occurred within that section of highway (MP 202-205). Consequently, the project may have had a minor impact on the results reported in this paper, but was likely not the major driver of the pattern we observed.

Winter conditions

Precipitation and temperature often are used to describe weather conditions (i.e. short-term patterns) and climate (i.e. long-term averages or normals) of areas (NOAA 2014). To document weather and climate during winter, we obtained temperature, precipitation, and snow depth data from weather stations that were located throughout the study area (Fig. 1). Temperature and precipitation data were provided by the National Climatic Data Center (NCDC 2013), and snow depth data were provided by the National Water and Climate Center (NWCC 2013). We defined the winter season as 1 December–31 March. We calculated temperature and precipitation normals by averaging annual winter data for 1981–2012, which was the range available for most weather stations in the study area. The snow depth normal represented a shorter temporal range (2003–2012) due to the limited data available for that variable. Temperature data were reported as the mean monthly temperature and precipitation data were reported as total precipitation for the winter season. Snow depth data represented the mean daily snow depth for the winter season.

We compared temperature, precipitation, and snow depth between winters using paired t-tests ($\alpha = 0.05$). When data did not meet the assumptions of the parametric t-test, we used the nonparametric Wilcoxon rank-sum test. We used the same approach for all comparisons in the paper, except for DVC data. When we compared differences in DVC

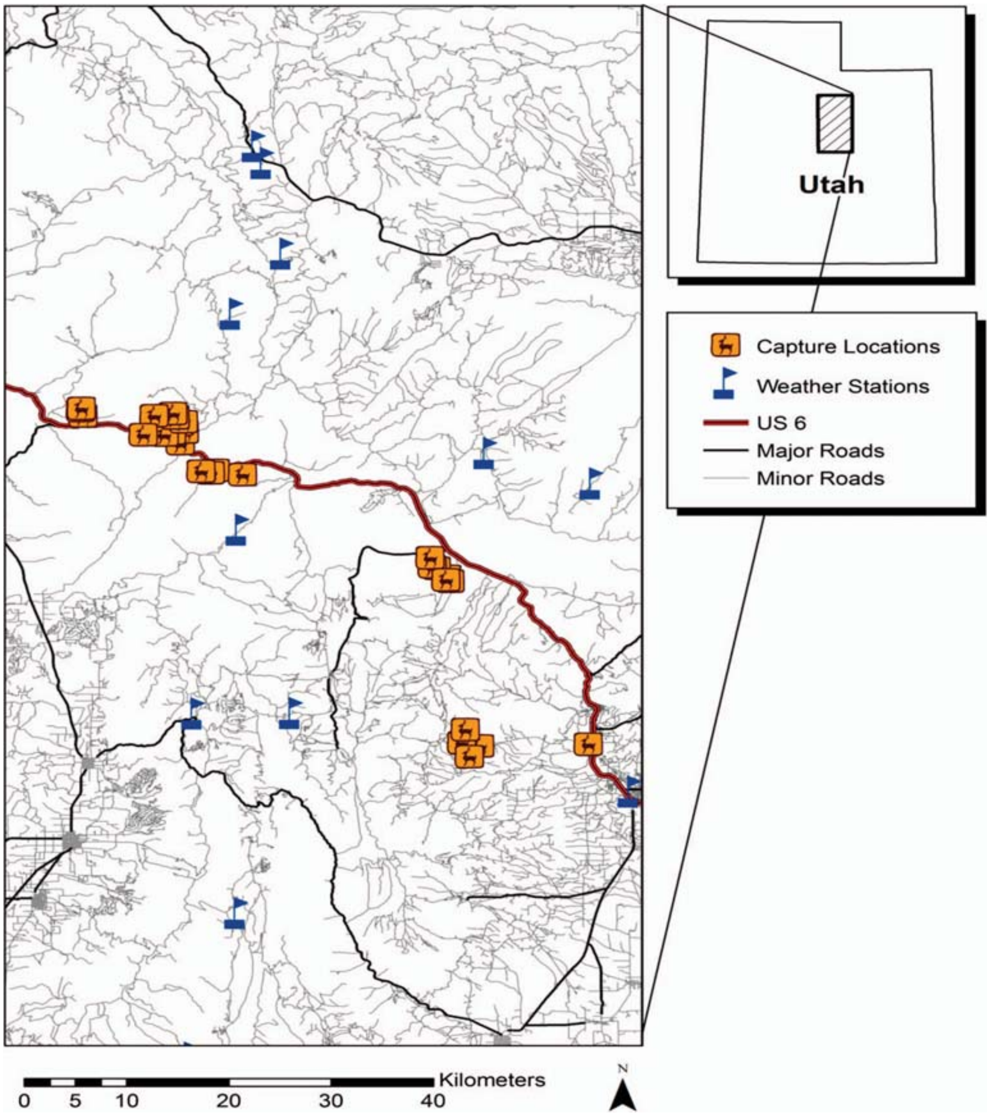

Figure 1. Locations of mule deer that were captured and instrumented with GPS telemetry collars, weather stations that were used to describe winter conditions, and roads in central Utah, USA.

data between winters, we used χ^2-tests. All statistical tests were performed in R ver. 2.14 (<www.r-project.org/>) and were purposely kept uncomplicated to increase the clarity of the results, as recommended by Guthery (2008).

Traffic volumes and deer abundance

Traffic volume data were obtained from the Utah Department of Transportation (UDOT) for the study area (UDOT 2012). Traffic volumes for roads were reported by UDOT as average annual daily traffic during each calendar year. We categorized roads as US 6, major roads and minor roads. Major roads were defined as having traffic volumes ≥ 500 vehicles day^{-1}. Minor roads were defined as having < 500 vehicles day^{-1} or roads that were unmonitored for traffic volume. We considered US 6 separately from other major roads because it had the highest traffic volumes of all roads within the study area, and because it has been the focus of DVC mitigation for several years.

Mule deer abundance was estimated annually by the Utah Division of Wildlife Resources (UDWR). During the study period, the UDWR collected survival, harvest, recruitment, and population structure data and used POP-II to model deer abundance within management units (Bernales et al. 2011). The modeling process did not include estimates of uncertainty. We used management unit totals to estimate the number of mule deer within our study area by weighting totals by the proportion of the management unit area that occurred within the boundaries of our study area.

Deer movements and survival

To document the movements and survival of deer in relationship to roads, 32 adult (>2 years) female mule deer were captured on winter ranges in the US 6 corridor (Fig. 1). Contractors employed by the UDWR captured deer using a standard helicopter and net gun technique

(Krausman and Hervert 1985). One additional deer was captured by UDWR biologists using chemical immobilization (Eberhardt et al. 1984). All deer were handled in accordance with guidelines for the use of mammals in research (Sikes and Gannon 2011), under permits held by the UDWR. Captured deer were instrumented with store-on-board global positioning system (GPS) collars. Collars were programmed to record one location every 8 h. Each tracking collar was also equipped with a very high frequency (VHF) transmitter and a mortality sensor. We monitored survival of deer weekly (Peterson and Messmer 2011).

All GPS locations were screened for accuracy and improbable locations were removed (Villepique et al. 2008). Using ArcGIS 10.1, we estimated road crossing rates (crossings week^{-1}) by overlaying each animal's movement path on a current road layer obtained from the Utah Automated Geographic Research Center (Utah AGRC 2012). Road crossing rates represent minimum estimates because the interval between locations was long enough that deer could have moved back and forth across roads without being detected.

We also documented elevation use by deer and distance that deer occurred from roads. Elevation for each location was recorded by the GPS collar. We used ArcGIS 10.1 to measure the Euclidean distance between deer locations and roads. When comparing differences between winters, we considered the individual animal as the experimental unit (Sawyer et al. 2006, 2009).

We estimated winter survival rates (1 December – 31 March) for deer using a known-fate analysis in Program Mark 6.1 (Cooch and White 2013). We fit models with crossing rates, distance to roads, and year, and compared them to an intercept-only model using Akaike information criterion (AIC) (Akaike 1973) with a correction for small sample sizes (Burnham and Anderson 2002). When nested models were separated by < 2 AIC$_c$ points and differed by only one parameter, we considered the model with an additional parameter as noncompeting and did not report it (Arnold 2010).

Deer–vehicle collisions

To index the number of DVCs that occurred on roads within the study area, we used carcass survey data that were collected by UDOT contractors. Carcass surveys have been conducted in Utah since at least 1998 (Bissonette and Rosa 2012). Surveys were performed using automobiles that were driven at posted speed limits by a single observer. During surveys, contractors were required to remove all carcasses that were detected on the road surface and the road shoulder. Contractors kept detailed records of deer carcass locations using GPS. Double-counting of deer carcasses was unlikely because reported carcasses were also removed from roads and deposited at local landfills. Within our study area, carcass surveys were conducted on US 6 and all major roads, but not on minor roads. DVC estimates from carcass surveys represent minimum estimates, because carcass survey totals have not been corrected for bias (e.g. detection, carcass persistence).

Results

Winter conditions

Data on winter conditions were collected from 12 weather stations throughout the study area (Fig. 1). Mean elevation of weather stations was 2484 m (n = 12, SD = 293). Normal winter temperature for the study area was –4.9°C (n = 384, SD = 8.4). Normal precipitation was 226 mm (n = 384, SD = 52), and normal snow depth was 891 mm (n = 50, SD = 359). Compared to normal conditions, temperatures during both winters were warmer (Fig. 2). However, precipitation and snow depth were both below normal during 2010–2011,but above normal during 2011–2012. When we compared the two winters to each other, temperature (t = –11.89, DF = 10, $p = < 0.001$), precipitation (t = 3.16, DF = 7, p = 0.016), and snow depth (t = 9.76, DF = 5, $p = < 0.001$) all differed significantly. The extent of the difference in weather conditions between winters was biologically meaningful; temperatures were 28% warmer (+ 1.1°C), precipitation was 50% less (–138 mm), and snow depths were 48% lower (–568 mm) during 2011–2012.

Traffic volumes and deer abundance

Traffic volumes on US 6 (t = 0.11, DF = 12, p = 0.915) and major roads (t = –0.32, DF = 61, p = 0.752) did not differ between years. Mean traffic volume for US 6 was 9216

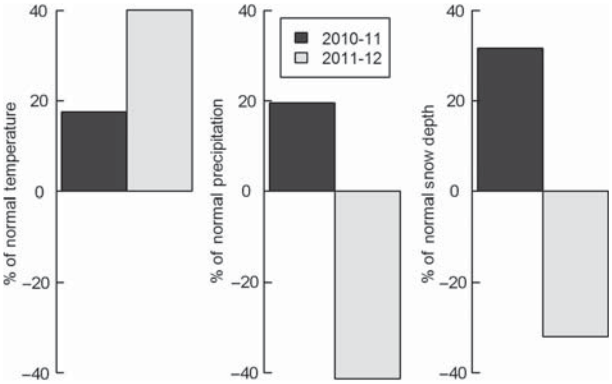

Figure 2. Percentage of normal temperature, precipitation, snow depth (mm) during winter 2010–2011 and 2011–2012 in central Utah, USA. Temperature was above normal for both winters (17–40%), but warmer in 2011–2012. Precipitation and snow depth were 20–32% above normal in 2010–2011 and 32–41% below normal in 2011–2012, resulting in largely dissimilar weather conditions for deer between winters.

vehicles day^{-1} ($n = 27$, $SD = 1965$) and for major roads it was 3625 vehicles day^{-1} ($n = 124$, $SD = 3214$). According to population estimates, mule deer abundance within the study area was 31 145 animals in 2010–2011 and 28 911 animals in 2011–2012, which represented a 7% decrease between years. There was also a marginal decrease (–3%) in mule deer abundance throughout the state.

Deer movements and survival

To document movements and survival of mule deer, 31 adult female deer were captured in December 2010 and one additional deer was captured in January 2011 (Fig. 1). The mean distance of deer capture locations to US 6 was 3.5 km ($n = 32$, $SD = 3.9$ km). GPS collars acquired spatial coordinates on 89% ($n = 40\,787$) of programmed attempts ($n = 40\,787$), and 87% of locations were 3D, indicating horizontal location error was generally < 20 m (Di Orio et al. 2003, Sawyer et al. 2009). From GPS movement data, we estimated crossing rates of deer on roads within the study area (Fig. 3). Crossings rates deceased 96 % between winters on US 6 ($W = 663$, $p < 0.001$). Crossing rates also decreased on major roads (–72%) and on minor roads (–12%) between winters, but differences were not statistically significant (major roads, $W = 464$, $p = 0.56$; minor roads, $W = 462.5$, $p = 0.81$).

There were also marked changes in habitat use by deer. Elevation use differed between winters ($t = –8.62$, $DF = 29$, $p < 0.001$). Deer occurred at a mean elevation of 1843 m ($n = 32$, $SD = 224$ m) during winter 2010–2011, but moved an average of 302 m (16%) higher in elevation during winter 2011–2012 to 2145 m ($n = 32$, $SD = 182$ m). Deer also occurred 55% farther from all roads during the second winter, but distance varied by road type. Deer were 213% (3.8 km) farther from US 6, 21% (1.6 km) farther from major roads, 42% (0.3 km) farther from minor roads compared to winter 2011–2012 (Fig. 4). The distance that deer occurred from US 6 ($W = 112.0$, $p < 0.001$) and major roads ($W = 301.5$, $p < 0.001$) differed significantly between winters, but we did not detect a difference for minor roads ($W = 415.0$, $p = 0.364$).

When we modeled survival for road and year effects, we found that crossing rate by deer on US 6 was the top predictor of survival (Table 1). According to model predictions, > 1.2 crossings week^{-1} began to substantially reduce deer survival (Fig. 4); although there was considerable uncertainty in survival estimates. Crossing rate on minor roads also had limited support (13% of model weight). However, it is unlikely that crossing minor roads is an actual driver of deer survival, because minor roads have low traffic volumes and few DVCs occur on these roads.

Deer–vehicle collisions

The number of deer carcasses reported on roads that were surveyed within the study area decreased 75% (234 carcasses) between 2010–2011 and 2011–2012. Additionally, the number of carcasses reported on US 6 ($\chi^2 = 140$, $DF = 1$, $p = < 0.001$) and major roads ($\chi^2 = 24$, $DF = 1$, $p = < 0.001$) differed significantly between winters. Reported carcasses decreased 91% (168 carcasses) on US 6 and 52% (66 carcasses) on major roads (Fig. 3). Furthermore, the number of reported carcasses in Utah differed between winters ($\chi^2 = 760$, $DF = 1$, $p = < 0.001$), with 73% (1316 carcasses) fewer carcasses reported during 2011–2012, indicating a statewide trend.

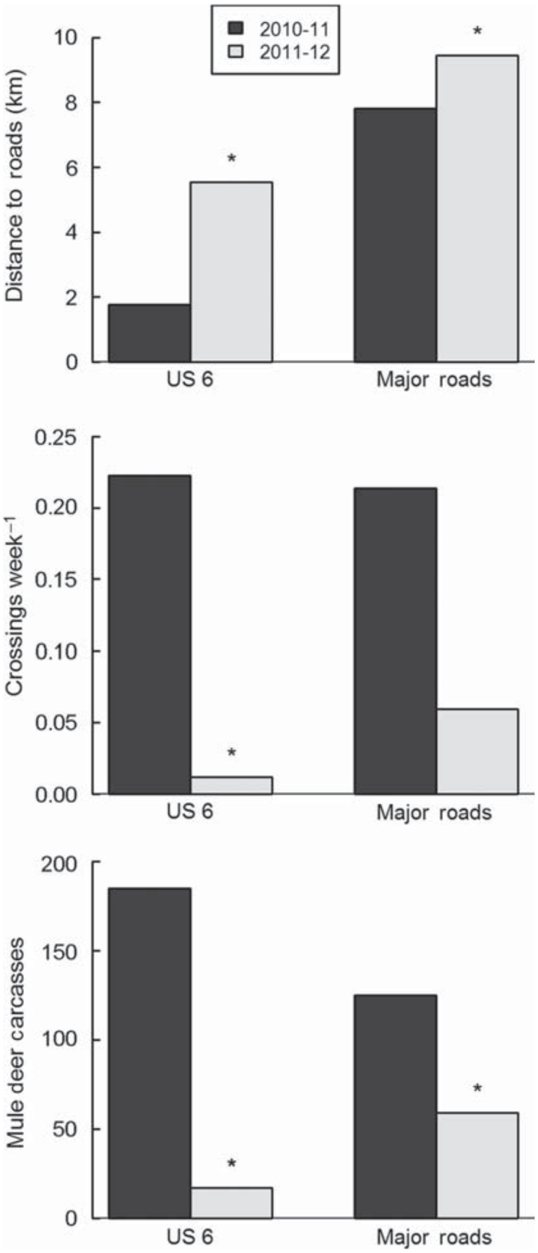

Figure 3. GPS telemetry was used to document road crossing rates and distance of mule deer to roads during winter 2010–2011 and 2011–2012 in central Utah, USA. Additionally, deer carcass surveys were conducted using automobiles to index deer–vehicle collision levels. Distance of deer to roads increased 21–213% between winters depending on road type. Subsequently, road crossing rates declined 12–96% and reported deer carcasses decreased 52–91%. Asterisks (*) indicate statistical significance at $\alpha = 0.05$.

Discussion

Deer–vehicle collisions are a significant management and conservation challenge in landscapes that have been altered

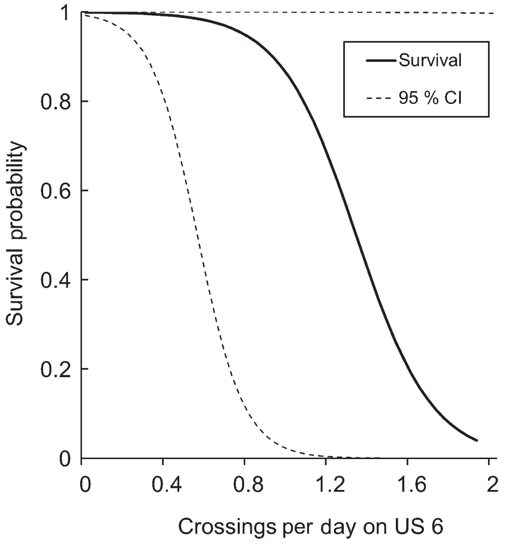

Figure 4. A known-fate model describing the relationship between mule deer survival and road crossing rates on US 6 in central Utah, USA. Model estimates indicate that crossing rates as low as 1.2 crossings week^{-1} can begin to substantially lower deer survival; however error bars indicate there is considerable uncertainty in model estimates.

by humans (Neumann et al. 2012). The rate at which DVCs occur is spatially and temporally variable (Biggs et al. 2004, Kassar and Bissonette 2005), and understanding the source of this variation is the key to effective mitigation that will enhance driver safety and reduce deer mortality. Our purpose in conducting this study was to examine how natural variation in weather during winter influenced deer distribution, movement patterns and DVC rates.

The study encompassed two consecutive winters during which weather conditions differed considerably. During the first winter, the study area was slightly warmer than average but had above average precipitation and snow depths. Alternatively during the second winter, precipitation and snow depth were below average, and temperatures were even warmer. This created a stark contrast in the amount of snow cover on the landscape, because on average snow depths were 568 mm lower during the second winter. It has been suggested that movements are impeded by snow depths greater than 250 mm, while depths greater than 500 mm essentially exclude mule deer use (Gilbert et al. 1970, Kie and Czech 2000). Given that snow depth is often patchy, especially on south facing slopes, it is conceivable that more resources were available for mule deer use during the second winter.

Table 1. Results of model selection (AICc and ΔAICc), model weights (w_i), and number of estimated parameters (K) for models of mule deer survival in relation to various road-related covariates during the winters of 2010–2011 and 2011–2012 in central Utah, USA. Deer crossing rate on US 6 was the highest supported model. Crossing rate on minor roads also had support but was likely not a substantial driver of deer survival, because minor roads had low traffic volumes and few deer–vehicle collisions.

Model structure	AICc	ΔAICc	w_i	K
Crossing US 6	23.72	0.00	0.28	2
Crossing minor roads	25.27	1.55	0.13	2
Distance to major roads	26.89	3.17	0.06	2
Crossing US 6 + Distance to US 6 + Year	26.99	3.28	0.05	4
Distance to minor roads	27.44	3.72	0.04	2
Distance to US 6	28.58	4.86	0.02	2
Year	29.13	5.41	0.02	2
Intercept	29.88	6.16	0.01	1
Crossing major roads	31.69	7.97	0.01	2

Movement allows deer to adjust to environmental variation in snow depth (Garrott et al. 1987, Brown 1992, van Moorter et al. 2013). In our study, deer wintered at higher elevations during the second winter, most probably because of relatively lower snow accumulations in those areas. As a result, the spatial distribution of deer in relationship to roads was affected, with deer occurring twice as far from US 6 and somewhat farther from major roads. Consequently, deer crossed roads with high traffic volumes less frequently (52–96% decrease) because fewer deer wintered adjacent to roads with high traffic volumes.

In our study area, deer that crossed US 6 less often had higher survival than deer that crossed more frequently. Additionally, relatively low road crossing rates (1.2 crossings week^{-1}) were enough to cause declines in survival; however, there was considerable uncertainty around survival estimates. These results suggest that roads with high traffic volumes pose a significant risk to deer safety and provide support that the reduction in DVCs we observed during the second winter was the result of deer crossing high volume roads less frequently. Additionally, the reduction in road crossings on US 6 between winters was essentially proportional to the reduction in DVCs, providing further support that changes in movement patterns of deer due to climatic variation were driving the observed changes.

While there was considerable support that variation in weather caused much of the difference in DVCs we observed between winters, DVC rates may have also been affected by changes in traffic volumes (Romin and Bissonette 1996a). It is possible that traffic volume decreases could have contributed to a decrease in DVC rates, because as traffic volume declines, roads become safer for deer to cross (Litvaitis and Tash 2008). According to UDOT estimates, however, traffic volumes were essentially unchanged between years; as a result, it is unlikely that variation in traffic volume contributed substantially to the pattern in DVCs we observed.

Variation in deer abundance also can produce marked changes in DVC rates (Jahn 1959, DeNicola and Williams 2008). Mule deer populations are highly variable in Utah (Austin 2010, Bernales et al. 2011) and not surprisingly, deer abundance differed between winters during the study. Deer abundance was higher during the first winter when DVC rates were high and lower during the second winter when DVC rates decreased. A reduction in deer abundance likely contributed some of the variation in DVC rates that was observed between winters. According to UDWR population estimates, however, mule deer abundance only decreased 7% between winters in our study area, which is considerably less than the 52% decrease in DVCs we observed on major roads and the 91% decrease we observed on US 6. Based on the results from current DVC studies (DeNicola and Williams 2008, Rolandsen et al. 2011), we would expect DVCs to decrease proportionally to changes in abundance, which did not occur in our study. Additionally, abundance during 2011–2012 may be underestimated and the rate of decrease (–7%) may be even smaller because deer were more dispersed and likely more difficult to detect in surveys during that winter (Habib et al. 2012). Due to these factors, we suggest that changes in deer abundance may have had a marginal effect on DVC rates but was not the major driver of the pattern we observed. However, our study was limited in both temporal and geographic scope. Future research should focus on long-term, broad-scale studies that quantify the relative importance of winter weather and abundance on DVC rates (Rolandsen et al. 2011).

Snow conditions, which can vary considerably between years, are a major factor influencing the movement patterns of mule deer in temperature climates (Garrott et al. 1987). More than 30 years ago, Reed and Woodard (1981) suggested winter weather was likely an important driver of DVC rates. The evidence from our study provides a mechanism by which variation in winter conditions contribute to variation in DVC rates between years. Deer in the study area occurred farther from roads and crossed high traffic volume roads less when snow depths were lower, which resulted in lower DVC rates. Because harvest quotas are often set by management agencies in the spring, these findings may help deer managers adjust harvest quotas annually to account increased vehicle-related mortality that occurs during winters with high precipitation and snow fall.

The response of mule deer to snow conditions may result in an ecological trap for deer during severe winters in landscapes that have roads with high traffic volumes (Schlaepfer et al. 2002). As deer move from areas with high snow accumulations to areas with low snow accumulations, movement and foraging become relatively more efficient, but if deer select habitats near roads with high traffic volumes, then survival and fitness may actually be reduced due to the increased probability of being involved in a vehicle collision. This problem can be mitigated with exclusionary fencing (> 2 m) that prevents deer from accessing road ways (McCollister and Van Manen 2010). Exclusionary fencing can reduce DVCs 80–90 % (Huijser et al. 2008), but fencing can be expensive and wildlife crossings, which are also relatively expensive, should be built at frequent intervals (~1.6 km) to retain landscape permeability for deer (Bissonette and Adair 2008). Researchers also have tried manipulating the spatial distribution of deer in relation to roads with winter feeding stations to decrease DVCs (Wood and Wolfe 1988). By placing feeding stations away from roads, DVC rates were reduced nearly 50%. However, winter feeding has significant economic costs, implications for pathogen transmission, and may degrade vegetation and alter migration patterns of deer (Peterson and Messmer 2007).

Another aspect of DVC mitigation is warning drivers of potentially dangerous situations (Mastro et al. 2008), but the dynamic nature of DVCs can make this a challenge. However, It would seem that the most effective DVC warning systems would be as dynamic as the phenomena they represent. Recent advances in DVC reporting systems have used smartphones to collect and transfer information, which have made current and accurate DVC data readily available for mitigation (Olson et al. 2014). Current DVC information from these databases could be used to create to a smartphone-based warning system that would indicate to drivers when they were entering a section of highway that was currently experiencing high rates of DVCs. Warning systems such as these could accurately represent the spatial and temporal variation that occurs in DVC patterns and may prove to be an effective area of research that could improve driver safety and reduce the number of deer killed.

References

Akaike, H. 1973. Maximum likelihood identification of Gaussian autoregressive moving average models. – Biometrika 60: 255–265.

Allen, R. E. and McCullough, D. R. 1976. Deer–car accidents in southern Michigan. – J. Wildl. Manage. 40: 317–325.

Arnold, T. W. 2010. Uninformative parameters and model selection using Akaike’s information criterion. – J. Wildl. Manage. 74: 1175–1178.

Austin, D. D. 2010. Mule deer: a handbook for Utah hunters and landowners. – Utah State Univ. Press.

Barrueto, M. et al. 2014. Anthropogenic effects on activity patterns of wildlife at crossing structures. – Ecosphere 5: art27.

Bernales, H. H. et al. 2011. Utah big game annual report 2011. – Utah Div. of Wildlife Resources.

Biggs, J. et al. 2004. Animal-related vehicle accidents at the Los Alamos National Laboratory, New Mexico. – Southwest. Nat. 49: 384–394.

Bissonette, J. A. and Adair, W. 2008. Restoring habitat permeability to roaded landscapes with isometrically-scaled wildlife crossings. – Biol. Conserv. 141: 482–488.

Bissonette, J. A. and Rosa, S. 2012. An evaluation of a mitigation strategy for deer–vehicle collisions. – Wildl. Biol. 18: 414–423.

Bissonette, J. A. et al. 2008. Assessment of costs associated with deer–vehicle collisions: human death and injury, vehicle damage and deer loss. – Hum.– Wildl. Confl. 2: 17–27.

Boeker, E. L. et al. 1972. Seasonal food habits of mule deer in southwestern New Mexico. – J. Wildl. Manage. 36: 56–63.

Brown, C. G. 1992. Movement and migration patterns of mule deer in southeastern Idaho. – J. Wildl. Manage. 56: 246–253.

Burnham, K. P. and Anderson, D. R. 2002. Model selection and multi-model inference: a practical information-theoretic approach. – Springer.

Case, R. M. 1978. Interstate highway road-killed animals: a data source for biologists. – Wildl. Soc. Bull. 6: 8–13.

Conover, M. R. 2001. Resolving human–wildlife conflicts: the science of wildlife damage management. – CRC Press.

Conover, M. R. et al. 1995. Review of human injuries, illnesses, and economic losses caused by wildlife in the United States. – Wildl. Soc. Bull. 23: 407–414.

Cooch, E. and White, G. 2013. Program MARK: a gentle introduction. <www.phidot.org/software/mark/docs/book/> accessed 19 July 2013.

DeNicola, A. J. and Williams, S. C. 2008. Sharpshooting suburban white-tailed deer reduces deer–vehicle collisions. – Hum.-Wildl. Interact. 2: 28–33.

Di Orio, A. P. et al. 2003. Performance of two GPS telemetry collars under different habitat conditions. – Wildl. Soc. Bull. 31: 372–379.

Eberhardt, L. E. et al. 1984. Movement and activity patterns of mule deer in the sagebrush-steppe region. – J. Mammal. 65: 404–409.

Garrott, R. A. et al. 1987. Movements of female mule deer in northwest Colorado. – J. Wildl. Manage. 51: 634–643.

Gilbert, P. F. et al. 1970. Effect of snow depth on mule deer in Middle Park, Colorado. – J. Wildl. Manage. 34: 15–23.

Griffith, G. E. and Omernik, J. M. 2011. Ecoregions of Utah (EPA). <www.eoearth.org/view/article/152226/> accessed 13 May 2013.

Groot Bruinderink, G. W. T. A. and Hazebroek, E. 1996. Ungulate traffic collisions in Europe. – Conserv. Biol. 10: 1059–1067.

Grovenburg, T. et al. 2008. Factors affecting road mortality of whitetailed deer in eastern South Dakota. – Human–Wildl. Interact. 2: 48–59.

Gruell, G. E. and Papez, N. J. 1963. Movements of mule deer in northeastern Nevada. – J. Wildl. Manage. 27: 414–422.

Guthery, F. S. 2008. Statistical ritual versus knowledge accrual in wildlife science. – J. Wildl. Managa. 72: 1872–1875.

Habib, T. J. et al. 2012. Detection and stratification approaches for aerial surveys of deer in prairie-parklands. – Wildl. Res. 39: 593–602.

Hansen, L. A. et al. 2012. Life in the fast lane: road crossing behavior of mule deer in a wildland–urban interface. – Los Alamos Natl Laboratory.

Huijser, M. P. et al. 2008. Wildlife–vehicle collision reduction study: report to Congress. – W. Transp. Inst.

Jahn, L. R. 1959. Highway mortality as an index of deer-population change. – J. Wildl. Manage. 23: 187–197.

Kassar, C. A. and Bissonette, J. A. 2005. Deer–vehicle crash hotspots in Utah: data for effective mitigation. – Utah State Univ.

Kie, J. G. and Czech, B. 2000. Mule and black-tailed deer. – In: Demarais, S. and Krausman, P. R. (eds), Ecology and management of large mammals in North America. Prentice-Hall, pp. 629–657.

Krausman, P. R. and Hervert, J. J. 1985. Capturing deer and mountain sheep with a net-gun. – J. Wildl. Manage. 13: 71–73.

Kucera, T. E. 1992. Influences of sex and weather on migration of mule deer in California. – Great Basin Nat. 52: 122–130.

Langley, R. L. et al. 2006. Risk factors associated with fatal animal–vehicle collisions in the United States, 1995–2004. – Wilderness Environ. Med. 17: 229–239.

Litvaitis, J. A. and Tash, J. P. 2008. An approach toward understanding wildlife–vehicle collisions. – Environ. Assess. 42: 688–697.

Lowry, J. H. et al. 2005. Southwest Regional Gap Analysis Project: final report on land cover mapping methods. – Utah State Univ.

Mastro, L. et al. 2008. Deer–vehicle collision prevention techniques. – Human–Wildlife Interact. 2: 80–92.

McCollister, M. F. and Van Manen, F. T. 2010. Effectiveness of wildlife underpasses and fencing to reduce wildlife–vehicle collisions. – J. Wildl. Manage. 74: 1722–1731.

Meisingset, E. L. et al. 2014. Targeting mitigation efforts: the role of speed limit and road edge clearance for deer–vehicle collisions. – J. Wildl. Manage. 78: 679–688.

Mysterud, A. 2004. Temporal variation in the number of car-killed red deer *Cervus elaphus* in Norway. – Wildl. Biol. 10: 203–211.

NCDC 2013. Climate data online. – Natl Clim. Data Cent. <www.ncdc.noaa.gov/cdo-web/> accessed 5 June 2013.

Neumann, W. et al. 2012. Difference in spatiotemporal patterns of wildlife road-crossings and wildlife–vehicle collisions. – Biol. Conserv. 145: 70–78.

Ng, J. W. et al. 2008. Landscape and traffic factors influencing deer–vehicle collisions in an urban environment. – Hum.–Wildl. Confl. 2: 34–47.

NOAA 2014. What is the difference between weather and climate? – Natl Ocean. Atmospheric Adm. <http://oceanservice.noaa.gov/facts/weather_climate.html> accessed 12 July 2014.

Noro, M. 2010. Analysis of deer ecology and landscape features as factors contributing to deer–vehicle collisions in Hokkaido, Japan. – Transportation Research Board.

NWCC 2013. Snotel data. – Natl Water Clim. Cent. <www.wcc.nrcs.usda.gov/> accessed 7 June 2013.

Olson, D. D. et al. 2014. Monitoring wildlife–vehicle collisions in the information age: how smartphones can improve data collection. – PLoS ONE 9: e98613.

Parker, K. L. et al. 1984. Energy expenditures for locomotion by mule deer and elk. – J. Wildl. Manage. 48: 474–488.

Peterson, C. and Messmer, T. A. 2007. Effects of winter-feeding on mule deer in northern Utah. – J. Wildl. Manage. 71: 1440–1445.

Peterson, C. and Messmer, T. A. 2011. Biological consequences of winter-feeding of mule deer in developed landscapes in northern Utah. – Wildl. Soc. Bull. 35: 252–260.

Reed, D. F. 1981. Conflicts with civilization. – In: Walmo, O. C. (ed.), Mule and black-tailed deer of North America. Univ. of Nebraska Press, pp. 509–545.

Reed, D. F. and Woodard, T. N. 1981. Effectiveness of highway lighting in reducing deer–vehicle accidents. – J. Wildl. Manage. 45: 721–726.

Rolandsen, C. M. et al. 2011. Large-scale spatiotemporal variation in road mortality of moose: is it all about population density? – Ecosphere 2: art113.

Romin, L. and Bissonette, J. A. 1996a. Deer–vehicle collisions: status of state monitoring activities and mitigation efforts. – Wildl. Soc. Bull. 24: 276–283.

Romin, L. A. and Bissonette, J. A. 1996b. Temporal and spatial distribution of highway mortality of mule deer on newly constructed roads at Jordanelle Reservoir, Utah. – W. N. Am. Nat. 56: 1–11.

Sawyer, H. et al. 2006. Winter habitat selection of mule deer before and during development of a natural gas field. – J. Wildl. Manage. 70: 396–403.

Sawyer, H. et al. 2009. Identifying and prioritizing ungulate migration routes for landscape-level conservation. – Ecol. Appl. 19: 2016–2025.

Sawyer, H. et al. 2013. A framework for understanding semi-permeable barrier effects on migratory ungulates. – J. Appl. Ecol. 50: 68–78.

Schlaepfer, M. A. et al. 2002. Ecological and evolutionary traps. – Trends Ecol. Evol. 17: 474–480.

Sikes, R. S. and Gannon, W. L. 2011. Guidelines of the American Society of Mammalogists for the use of wild mammals in research. – J. Mammal. 92: 235–253.

Stewart, K. M. et al. 2010. Spatial distributions of mule deer and North American elk: resource partitioning in a sage-steppe environment. – Am. Midl. Nat. 163: 400–412.

Sullivan, J. M. 2011. Trends and characteristics of animal–vehicle collisions in the United States. – J. Safety Res. 42: 9–16.

Thomas, T. R. and Irby, L. R. 1990. Habitat use and movement patterns by migrating mule deer in southeastern Idaho. – Northwest Sci. 64: 19–27.

UCCW 2009. Utah precipitation. – Utah Cent. Clim. Weather. <http://utahweather.org/UWC/lightning_precipitation/precipitation.html> accessed 17 July 2013.

UCCW 2013. Climate of Utah: NWS description of Utah's climate. – Utah Cent. Clim. Weather. <http://utahweather.org/climatology/climate-of-utah/> accessed 16 July 2013.

UDOT 2012. Traffic on Utah's highways. – Utah Dep. Transp. <www.udot.utah.gov/> accessed 1 July 2013.

Utah AGRC. 2012. Roads and highway system. – Utah Autom. Geogr. Ref. Cent. <http://gis.utah.gov/> accessed 6 June 2012.

van Moorter, B. et al. 2013. Understanding scales of movement: animals ride waves and ripples of environmental change. – J. Anim. Ecol. 82: 770–780.

Villepique, J. T. et al. 2008. Evaluating GPS collar error: a critical evaluation of Televilt POSREC-Science ™ collars and a method for screening location data. – Calif. Fish Game 94: 155–168.

Wood, P. and Wolfe, M. L. 1988. Intercept feeding as a means of reducing deer–vehicle collisions. – Wildl. Soc. Bull. 16: 376–380.