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ASSESSING VEHICLE-RELATED MORTALITY OF MULE DEER IN UTAH

by

Daniel D. Olson

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Wildlife Biology

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2013

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ABSTRACT

Assessing Vehicle-Related Mortality of Mule Deer in Utah

by

Daniel D. Olson, Doctor of Philosophy

Utah State University, 2013

Major Professor: Dr. John A. Bissonette
Department: Wildland Resources

In Utah, considerable amounts of mule deer habitat are now bisected by roads with increasing traffic volumes. Mule deer are commonly involved in vehicle collisions, and there is concern that roads may be impacting populations. The focus of my research was to: 1) estimate the number of vehicle collisions involving deer, 2) examine the demographic effects of deer-vehicle collisions, 3) determine how movements and survival were impacted by roads, and 4) create an electronic, smartphone-based system for reporting vehicle collisions. Great uncertainty exists with most deer-vehicle collision estimates. In chapter 2, I estimated the number of deer-vehicle collisions using carcass surveys, while accounting for several sources of bias to improve accuracy. I estimated that 2-5 % of the statewide deer population was killed in vehicle collisions annually. The effect that vehicle collisions have on deer abundance depended not only the number of deer killed but also on the demographic groups removed. In chapter 3, I found that 65 % of deer killed in vehicle collisions were female and 40 % were adult females. Because female deer, especially adults, are drivers of population growth, these data suggest vehicle collisions could significantly affect population abundance. However I was unable to detect a decreasing trend in deer abundance. Deer have distinct movement patterns that affect their distribution in relationship to roads. In chapter 4, I analyzed deer movements during two consecutive winters to

determine what effect climate had on deer movements and vehicle collision rates. I observed that as snow depth decreased, the distance that deer occurred from roads increased. As a result road crossing rates declined, as did the number of vehicle collisions. My data suggest a causal mechanism by which winter conditions affect deer-vehicle collision rates. Currently there is a need for efficient wildlife-vehicle collision data collection. In chapter 5, I discussed the development and testing of a smartphone-based system for reporting wildlife-vehicle collision data. The WVC Reporter system consisted of a mobile web application for data collection, a database for centralized storage of data, and a desktop application for viewing data. The system improved data accuracy and increased efficiency.

(176 pages)

PUBLIC ABSTRACT

Assessing Vehicle-Related Mortality of Mule Deer in Utah

Roads are essential in modern societies, but as populations grow and traffic volumes rise, roads will continue to be built and expanded. As a result, the effects that roads have on wildlife will likely intensify, making it imperative that managers understand those effects so mitigation can be directed accordingly. In Utah, considerable areas of mule deer (*Odocoileus hemionus*) habitat have been bisected by roads. Mule deer are commonly involved in vehicle collisions and there is concern that roads and vehicle traffic are impacting populations. This project was conducted to determine the number and demographic effects of deer-vehicle collisions, to examine how movements and survival of deer were impacted by roads, and to develop a smartphone-based reporting system for wildlife-vehicle collisions. Accurate estimates of DVCs are needed to effectively mitigate the effects of roads, but great uncertainty exists with most deer-vehicle collision estimates. I estimated the number of deer-vehicle collisions using carcass surveys, while accounting for several sources of bias to improve accuracy. I estimated that 2-5 % of the statewide deer population was killed in vehicle collisions annually. The effect that vehicle collisions have on deer abundance depended not only on the number of deer killed but also on the demographic groups removed. I found that 65 % of deer killed in vehicle collisions were female and 40 % were adult females. As female deer are the primary drivers of population growth, my data suggest vehicle collisions could significantly affect population abundance. However I was unable to detect a decreasing trend in deer abundance. Deer have distinct movement patterns that affect their distribution in relationship to roads. I analyzed deer movements during two consecutive winters (2010-11 & 2011-12) to determine what effect climate had on deer movements and vehicle collision rates. I observed that as snow depth decreased, the distance that deer occurred from roads increased. As a result road crossing rates declined, as did the number of

vehicle collisions. This suggests a causal mechanism by which winter conditions influence vehicle collision rates. Currently there is a need for an efficient wildlife-vehicle collision data collection. I envisioned and, working with colleagues, helped develop a smartphone-based system for reporting wildlife-vehicle collision data. The WVC Reporter system consisted of a mobile web application for data collection, a database for centralized storage of data, and a desktop application for viewing data. The system greatly improved accuracy and increased efficiency of data collection efforts, which will likely result in improved mitigation and ultimately increased safety for motorists and deer.

Daniel D. Olson

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Daniel D. Olson

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CHAPTER 1

INTRODUCTION

Roads are a fundamental component of modern societies (Larsson et al. 2010). They facilitate the movement of people and goods, encourage economic development, and enrich social interactions (Forman et al. 2003). Each day in the United States, as many as 13 million km are driven and 31 million metric tons of freight are moved on the Nation's 6.5 million km of roads (U.S. DOT 2010). The road network in the United States has expanded ~0.3 % annually, resulting in nearly 20,000 km of new roads each year; traffic volumes have also increased ~2.0 % annually (U.S. DOT 2010), which is congruent with the long term trend of capacity on roads increasing more rapidly than construction of new roads (Forman et al. 2003).

While growth and expansion of roads provides many benefits for people, roads can have mixed effects on wildlife populations (Forman and Alexander 1998, Trombulak and Frissell 2000). Roads apparently benefit some species, because vegetation is often modified adjacent to roads. For example, Adams and Geis (1983) observed small mammal densities were higher in road right-of-ways than in other habitats. Although roads do benefit certain species, the direct and indirect ecological effects of roads appear to be mostly negative for wildlife (Putman 1997, Forman and Alexander 1998, Trombulak and Frissell 2000, Taylor and Goldingay 2010).

The negative direct effects of roads include habitat loss due to the construction of new roads and the expansion of existing roads (Forman 2000), and increased mortality rates due to vehicle collisions (Fahrig and Rytwinski 2009). Forman et al. (1995) estimated that greater than 1 % of the land area in the United States has been converted to road corridors. More than 1 million vertebrates are killed in vehicle collisions daily (Forman and Alexander 1998).

The indirect effects of roads are often subtle and more difficult to demonstrate than direct effects (Forman et al. 2003), because indirect effects can result from multi-causal pathways and

may have significant time lags (Bissonette and Storch 2002, Didham et al. 2012). Indirect effects of roads include habitat degradation and fragmentation. Degradation is the process by which habitat decreases in quality over time, and if not reversed can result in habitat loss (Lindenmayer and Fischer 2006). Wildlife habitat adjacent to roads can be degraded by light, sound, and chemical pollution from vehicle traffic, as well as by changed vegetation (Forman and Alexander 1998, Rheindt 2003, Longcore and Rich 2004). Roads may also facilitate the spread of exotic and invasive species that change the quality of wildlife habitat (Mortensen et al. 2009). Furthermore, human activities such as hunting, poaching, camping, and off-road vehicle use are often higher near roads, which may cause some species to avoid areas adjacent to roads (Trombulak and Frissell 2000, Rowland et al. 2005). As a result, the influence of roads extends beyond the road surface; indeed Forman (2000) estimated that 20 % of the land area in United States has been influenced by roads.

Habitat fragmentation may also negatively impact wildlife populations (Lindenmayer and Fischer 2006). The term habitat fragmentation has been parsed into habitat loss and habitat arrangement by some authors (Fahrig 2003, 2013), but I am using the term to refer to the collective effects on habitats. Habitat fragmentation can occur when roads bisect otherwise continuous habitat, creating semipermeable or impermeable barriers to wildlife movements (Sawyer et al. 2013). When roads become barriers to wildlife movement, the ability of species to disperse, migrate, forage, and find mates is often diminished (Baur and Baur 1990, Ball and Dahlgren 2002, Rondinini and Doncaster 2002). The disruption of these processes can decrease individual fitness and ultimately population abundance, as well as create discontinuous, more isolated subpopulations with reduced genetic diversity (Keller and Largiadèr 2003, Epps et al. 2005, Roedenbeck and Voser 2008). Species that are most affected by habitat fragmentation

caused by roads are those that avoid roads or that transverse expansive areas to acquire adequate resources (Forman et al. 2003, Jaeger et al. 2005, Fahrig and Rytwinski 2009).

Deer (Cervidae) are broadly distributed throughout North America (Geist 1998), and in temperate climates may require large areas for optimal fitness (Sawyer et al. 2009). Consequently, many deer populations have been affected by the influence of roads. Vehicle collisions are one the most conspicuous road-related effects and often generate great public interest because they affect humans directly (Conover et al. 1995, Forman et al. 2003). In the United States, there are an estimated 1-2 million vehicle collisions with large animals each year, most of which involve deer (Conover 2001, Huijser et al. 2008). Economic costs associated with these collisions exceed \$8 billion (USD) annually (Huijser et al. 2008). Given the large number of deer-vehicle collisions (DVCs) that occur each year, there is considerable concern for public safety, because injuries to drivers and passengers occur in ~5 % of reported deer-vehicle collisions (Bissonette et al. 2008). Additionally, human fatalities have risen to ~200 annually in the United States (Langley et al. 2006).

Currently, there is a critical need to improve DVC data collection and estimates (Bissonette and Cramer 2008, Gunson et al. 2009), because DVC data are the underpinning of mitigation projects that protect both drivers and wildlife (Ford et al. 2009). Gathering DVC data, however, is challenging because DVCs occur over broad areas, during all seasons of the year, and sometimes in large numbers. Additionally, many animals injured by vehicle collisions subsequently leave the immediate road area and die (Myers 1969).

DVC data from accident reports, insurance claims, and carcass surveys have been used to estimate the number of DVCs (Knapp et al. 2007, West 2008, State Farm 2012), but there is considerable uncertainty of how well these data sources reflect the actual number of DVCs that are occurring (Huijser et al. 2007). All of the commonly used DVC data sources have intrinsic

biases that generally result in uncorrected totals being only a fraction of the actual number of DVCs (Knapp et al. 2007, Donaldson and Lafon 2010). Accurate DVC estimates are needed to inform DVC mitigation, and estimates can be improved considerably by accounting for biases in data collection and reporting (Huijser et al. 2007). Currently, many management agencies still collect DVC data on paper forms (Huijser et al. 2007), which is inefficient and typically results in avoidable inaccuracies. Given the recent advances that have taken place in mobile communications and electronics, it seems promising that the collection of vehicle collision data for deer and other wildlife can be substantially enhanced by incorporating modern advances such as smartphones.

The majority (92 %) of deer involved in vehicle collisions are killed as result of injuries sustained (Allen and McCullough 1976), but vehicle-related mortality does not necessarily cause deer populations to decline. Deer have relatively high reproductive rates and generally can sustain some mortality from anthropogenic causes without altering long-term abundance trends (Carpenter 2000, Erickson et al. 2003). For example, white-tailed deer are commonly involved in vehicle collisions throughout North America (Bashore et al. 1985, DeNicola and Williams 2008, McShea et al. 2008), and despite these losses, the species has generally increased in abundance and expanded its distribution (McCabe and McCabe 1997, McClure et al. 1997). However one subspecies of white-tailed deer, the endangered Key deer (*Odocoileus virginianus clavium*), has experienced vehicle-related mortality rates of 50-74 % which threatened population persistence (Lopez et al. 2003). Additionally in Utah, Peterson and Messmer (2011) reported that vehicle-related mortality was the leading cause of death (34% of mortality) for female deer in their study area, but they did not attempt to demonstrate a population-level effect (Peterson and Messmer 2011). While few studies have documented that vehicle-related mortality causes population

declines in deer, it remains a potentially important factor to consider because it affects deer populations and human safety directly.

Roads can also affect the daily and seasonal movements of deer, but species may vary in their response (Wisdom et al. 2004). For example, it was commonly believed that both mule deer and elk (*Cervus elaphus*) avoided roads based on early research conducted using pellet counts to describe use (Rost and Bailey 1979). However, more recent studies using modern methods found that elk generally avoided roads, but mule deer actually selected areas near roads (Wisdom et al. 2004, Tull and Krausman 2007, Stewart et al. 2010). The reasons why mule deer and elk differ in their response to roads are unclear. One suggestion is that socially dominant elk exclude mule deer from using habitats that are farther from roads (Wisdom et al. 2004, Stewart et al. 2010).

In temperate climates, many deer are migratory (Gruell and Papez 1963, Kucera 1992, Sawyer et al. 2009) and have distinct seasonal movement patterns that affect their spatial distribution in relationship to roads (Stewart et al. 2010). For example in summer, mule deer typically use high elevation ranges with abundant resources (Boeker et al. 1972). Summer ranges are often more remote, higher in elevation, and farther from roads (Stewart et al. 2010). In early to late fall, mule deer generally move from high elevation ranges, largely in response to seasonally declining resource quality, as well as 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 south 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 as a result deer are often closer to roads with high traffic volumes during winter (Reed 1981). Movements may vary annually as well (Russell 1932). 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). Changes in deer distributions and movements patterns can affect the number of DVCs that occur (Biggs et al. 2004, Mysterud 2004).

Utah, which is inhabited by several cervid species including mule deer, is located in the heart of the southwestern United States on the western edge of the Rocky Mountains in the Intermountain Basin. Currently the majority of the state is rural, but Utah is the 3rd fastest growing state in the United States and is rapidly becoming urbanized (Leydsman McGinty 2009, U. S. Census Bureau 2010, Iowa State University 2013). The growing human population has increased demand for transportation, and traffic volumes have double in the past 30 years (UDOT 2010). In 2010, it was estimated that 42.8 billion km were driven on 73,413 km of roads in the state (UDOT 2010, Pope and McEwan 2012). Deer-vehicle collisions are common in Utah and result in significant economic costs (Romin and Bissonette 1996). For example, the overall cost for 13,020 collisions over 6 years (1996-2001) was \$45,175,454, resulting in an estimated average cost per year of \$7,529,242 and a mean cost per collision of \$3,470 (Bissonette et al. 2008). Given changes in the consumer price index, costs in 2013 would be ~48.8 % higher or \$11,203,512 per year (Bureau of Labor Statistics 2013). Most DVCs in Utah involve mule deer (West 2008).

In Utah, mule deer are the most abundant deer species (~300,000 individuals) and are broadly distributed. Consequently, much of the distribution of mule deer in Utah is bisected with roads (Fig. 1.1). Because mule deer are commonly involved in vehicle collisions and traffic volumes are increasing on roads in Utah, there was genuine concern that roads may be impacting deer populations in the state. In 2009, the USGS Utah Cooperative Fish and Wildlife Research Unit at Utah State University and the Utah Division of Wildlife Resources began this study to address knowledge gaps on the effects of roads on mule deer. The primary objectives were to 1)

estimate more accurately the number of DVCs involving mule deer, 2) examine the demographic effects of DVCs on mule deer, 3) determine how movements and survival of mule deer were impacted by roads, and 4) create an electronic, smartphone-based system for reporting DVCs.

In chapter 2, I estimated the number of DVCs involving mule deer in Utah using carcass surveys conducted with automobiles and all-terrain vehicles. I accounted for carcass detection, retention, and persistence to improve the accuracy of DVC estimates. I also compared carcass survey estimates to other commonly used DVC data sources (i.e., accident reports and insurance claims) to determine the bias associated with them.

In chapter 3, I examined the demographic effects of vehicle-related mortality on mule deer in Utah. Using carcass survey data, I estimated the proportion of deer in each demographic group that was involved in vehicle collisions. I compared surveys of live deer to carcass surveys to determine if deer demographic groups were being killed in vehicle collisions according to their availability. I also compared vehicle collision rates for mule deer, elk, and moose (*Alces alces*), to determine if deer were more vulnerable to vehicle collisions than other cervid species in the state. Finally, I examined abundance estimates of mule deer to determine if increasing traffic volumes were potentially affecting the statewide deer population.

In chapter 4, I described the effect that winter climate has on deer movements and survival in relationship to roads and vehicles in central Utah. I used meteorological data from local weather stations to describe temperature, precipitation, and snow depth within the study area. I monitored deer movements with GPS telemetry to document distance of deer to roads, elevation use, and road crossing rates. I also described changes in deer abundance and traffic volumes that occurred during the study, which were potentially confounding variables.

In chapter 5, I discussed the development and testing of a smartphone-based system for reporting wildlife-vehicle collision data that was called the WVC Reporter. The WVC Reporter

system consists of a mobile web application for data collection, a database for centralized storage of data, and a desktop web application for viewing data. I tested the spatial accuracy of smartphones that were used for data collection. I also described data entry times and errors, and compared smartphone-based data collection with traditional methods. Finally, I discussed the costs and benefits of using the WVC Reporter for data collection.

My dissertation is written in multiple-chapter format. Chapters 1, 2, 3, 6 were written according to current guidelines in use by the Journal of Wildlife Management. Chapter 4 was written for Ecology and Society. Chapter 5 was written for PlosOne. All chapters follow the guidelines for the appropriate journals

LITERATURE CITED

- Adams, L. W., and A. D. Geis. 1983. Effects of roads on small mammals. *The Journal of Applied Ecology* 20:403.
- Allen, R. E., and D. R. McCullough. 1976. Deer-car accidents in southern Michigan. *Journal of Wildlife Management* 40:317–325.
- Ball, J. P., and J. Dahlgren. 2002. Browsing damage on pine (*Pinus sylvestris* and *P. contorta*) by a migrating moose (*Alces alces*) population in winter: relation to habitat composition and road barriers. *Scandinavian Journal of Forest Research* 17:427–435.
- Bashore, T. L., W. M. Tzilkowski, and E. D. Bellis. 1985. Analysis of deer-vehicle collision sites in Pennsylvania. *Journal of Wildlife Management* 49:769–774.
- Baur, A., and B. Baur. 1990. Are roads barriers to dispersal in the land snail *Arianta arbustorum*? *Canadian Journal of Zoology* 68:613–617.
- Biggs, J., S. Sherwood, S. Michalak, L. Hansen, and C. Bare. 2004. Animal-related vehicle accidents at the Los Alamos National Laboratory, New Mexico. *The Southwestern Naturalist* 49:384–394.

- Bissonette, J. A., and I. Storch. 2002. Fragmentation: is the message clear? *Conservation Ecology* 6:14.
- Bissonette, J. A., and P. C. Cramer. 2008. Evaluation of the use and effectiveness of wildlife crossings. National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, D.C., USA.
- Bissonette, J. A., C. A. Kassar, and J. C. Cook. 2008. Assessment of costs associated with deer-vehicle collisions: human death and injury, vehicle damage, and deer loss. *Human-Wildlife Conflicts* 2:17–27.
- Boeker, E. L., V. E. Scott, H. G. Reynolds, and B. A. Donaldson. 1972. Seasonal food habits of mule deer in Southwestern New Mexico. *Journal of Wildlife Management* 36:56–63.
- Brown, C. G. 1992. Movement and migration patterns of mule deer in southeastern Idaho. *Journal of Wildlife Management* 56:246–253.
- Bureau of Labor Statistics. 2013. CPI inflation calculator. United States Department of Labor. <http://www.bls.gov/data/inflation_calculator.htm>. Accessed 10 Sep 2013.
- Carpenter, L. H. 2000. Harvest management goals. Pages 192–213 *in* S. Demarais and P. R. Krausman, editors. *Ecology and management of large mammals in North America*. Prentice Hall, Upper Saddle River, New Jersey, USA.
- Conover, M. R., W. C. Pitt, K. K. Kessler, T. J. DuBow, and W. A. Sanborn. 1995. Review of human injuries, illnesses, and economic losses caused by wildlife in the United States. *Wildlife Society Bulletin* 23:407–414.
- Conover, M. R. 2001. *Resolving Human-Wildlife Conflicts: The Science of Wildlife Damage Management*. CRC Press, Boca Raton, Florida, USA.
- DeNicola, A. J., and S. C. Williams. 2008. Sharpshooting suburban white-tailed deer reduces deer-vehicle collisions. *Human-Wildlife Interactions* 2:28–33.

- Didham, R. K., V. Kapos, and R. M. Ewers. 2012. Rethinking the conceptual foundations of habitat fragmentation research. *Oikos* 121:161–170.
- Donaldson, B., and N. Lafon. 2010. Personal digital assistants to collect data on animal carcass removal from roadways. *Transportation Research Record: Journal of the Transportation Research Board* 2147:18–24.
- Epps, C. W., P. J. Palsbøll, J. D. Wehausen, G. K. Roderick, R. R. Ramey, and D. R. McCullough. 2005. Highways block gene flow and cause a rapid decline in genetic diversity of desert bighorn sheep. *Ecology Letters* 8:1029–1038.
- Erickson, G. L., J. R. Heffelfinger, and J. H. Ellenberger. 2003. Potential effects of hunting and hunt structure on mule deer abundance and demographics. Pages 119–138 in J. C. deVos, M. R. Conover, and N. E. Headrick, editors. *Mule deer conservation: issues and management*. Jack H. Berryman Institute Press, Logan, Utah, USA.
- Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. *Annual review of Ecology, Evolution, and Systematics* 34:487–515.
- Fahrig, L., and T. Rytwinski. 2009. Effects of roads on animal abundance: an empirical review and synthesis. *Ecology and Society* 14:21.
- Fahrig, L. 2013. Rethinking patch size and isolation effects: the habitat amount hypothesis. *Journal of Biogeography* 40:1649–1663.
- Ford, A. T., A. P. Clevenger, and A. Bennett. 2009. Comparison of methods of monitoring wildlife crossing-structures on highways. *Journal of Wildlife Management* 73:1213–1222.
- Forman, R. T. T., D. S. Friedman, D. Fitzhenry, J. D. Martin, A. S. Chen, and L. E. Alexander. 1995. Ecological effects of roads: toward three summary indices and an overview for North America. Pages 40–54 in K. Canter, editor. *Habitat fragmentation and*

infrastructure proceedings. Ministry of Transport, Public Works and Water Management, The Hague, Netherlands.

- Forman, R. T. T. 2000. Estimate of the area affected ecologically by the road system in the United States. *Conservation Biology* 14:31–35.
- Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics* 29:207–231.
- Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. *Road Ecology: Science and Solutions*. Island Press, Washington, D.C., USA.
- Garrott, R. A., G. C. White, R. M. Bartmann, L. H. Carpenter, and A. W. Alldredge. 1987. Movements of female mule deer in northwest Colorado. *Journal of Wildlife Management* 51:634–643.
- Geist, V. 1998. *Deer of the world: their evolution, behaviour and ecology*. Stackpole Books, Mechanicsburg, Pennsylvania, USA.
- Gilbert, P. F., O. C. Wallmo, and R. B. Gill. 1970. Effect of snow depth on mule deer in Middle Park, Colorado. *Journal of Wildlife Management* 34:15–23.
- Gruell, G. E., and N. J. Papez. 1963. Movements of mule deer in northeastern Nevada. *Journal of Wildlife Management* 27:414.
- Gunson, K. E., A. P. Clevenger, A. T. Ford, J. A. Bissonette, and A. Hardy. 2009. A comparison of data sets varying in spatial accuracy used to predict the occurrence of wildlife-vehicle collisions. *Environmental Management* 44:268–277.

- Huijser, M. P., M. E. Wagner, A. Hardy, A. P. Clevenger, and J. A. Fuller. 2007. Animal-vehicle collision data collection throughout the United States and Canada. Transportation Research Board, Washington, D.C., USA.
- Huijser, M. P., P. T. McGowen, J. Fuller, A. Hardy, and A. Kociolek. 2008. Wildlife-vehicle collision reduction study: report to Congress. Western Transportation Institute, Bozeman, Montana, USA
- Iowa State University. 2013. Urban percentage of the population for states, historical. Iowa State University of Science and Technology.
<<http://www.icip.iastate.edu/tables/population/urban-pct-states>>. Accessed 10 Sep 2013.
- Jaeger, J. A. G., J. Bowman, J. Brennan, L. Fahrig, D. Bert, J. Bouchard, N. Charbonneau, K. Frank, B. Gruber, and K. T. von Toschanowitz. 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. *Ecological Modelling* 185:329–348.
- Keller, I., and C. R. Largiadèr. 2003. Recent habitat fragmentation caused by major roads leads to reduction of gene flow and loss of genetic variability in ground beetles. *Proceedings of the Royal Society of London. Series B: Biological Sciences* 270:417–423.
- Knapp, K., C. Lyon, A. Witte, and C. Kienert. 2007. Crash or carcass data: critical definition and evaluation choice. *Transportation Research Record: Journal of the Transportation Research Board* 2019:189–196.
- Kucera, T. E. 1992. Influences of sex and weather on migration of mule deer in California. *Great Basin Naturalist* 52:122–130.
- Langley, R. L., S. A. Higgins, and K. B. Herrin. 2006. Risk factors associated with fatal animal-vehicle collisions in the United States, 1995–2004. *Wilderness & Environmental Medicine* 17:229–239.

- Larsson, P., S. W. A. Dekker, and C. Tingvall. 2010. The need for a systems theory approach to road safety. *Safety Science* 48:1167–1174.
- Leydsman McGinty, E. I. 2009. Urbanization in Utah. Pages 153–156 *in* R. E. Banner, B. D. Baldwin, and E. I. Leydsman McGinty, editors. *Rangelands resources of Utah*. Utah State University Cooperative Extension Service, Logan, Utah, USA.
- Lindenmayer, D. B., and J. Fischer. 2006. *Habitat fragmentation and landscape change: an ecological and conservation synthesis*. Island Press, Washington, D.C., USA.
- Longcore, T., and C. Rich. 2004. Ecological light pollution. *Frontiers in Ecology and the Environment* 2:191–198.
- Lopez, R. R., M. E. P. Vieira, N. J. Silvy, P. A. Frank, S. W. Whisenant, and D. A. Jones. 2003. Survival, mortality, and life expectancy of Florida key deer. *Journal of Wildlife Management* 67:34–45.
- McCabe, T. R., and R. E. McCabe. 1997. Recounting whitetails past. Pages 11–26 *in* W. J. McShea, H. B. Underwood, and J. H. Rappole, editors. *The science of overabundance: deer ecology and population management*. Smithsonian Institution Press, Washington, D.C., USA.
- McClure, M. F., J. A. Bissonette, M. R. Conover, and D. D. Austin. 1997. Range expansion of white-tailed deer (*Odocoileus virginianus*) into urban and agricultural areas of Utah. *Western North American Naturalist* 57:278–280.
- McShea, W. J., C. M. Stewart, L. J. Kearns, S. Liccioli, and D. Kocka. 2008. Factors affecting autumn deer–vehicle collisions in a rural Virginia County. *Human-Wildlife Conflicts* 2:110–121.
- Mortensen, D. A., E. S. J. Rauschert, A. N. Nord, and B. P. Jones. 2009. Forest roads facilitate the spread of invasive plants. *Invasive Plant Science and Management* 2:191–199.

- Myers, G. T. 1969. Deer-auto accidents: serious business. *Colorado Outdoors* 18:38–40.
- Mysterud, A. 2004. Temporal variation in the number of car-killed red deer *Cervus Elaphus* in Norway. *Wildlife Biology* 10:203–211.
- Parker, K. L., C. T. Robbins, and T. A. Hanley. 1984. Energy expenditures for locomotion by mule deer and elk. *Journal of Wildlife Management* 48:474–488.
- Peterson, C., and T. A. Messmer. 2011. Biological consequences of winter-feeding of mule deer in developed landscapes in northern Utah. *Wildlife Society Bulletin* 35:252–260.
- Pope, C., and A. McEwan. 2012. 2012 UDOT annual statistical summary. Utah Department of Transportation, Salt Lake City, Utah, USA.
- Putman, R. J. 1997. Deer and road traffic accidents: options for management. *Journal of Environmental Management* 51:43–57.
- Reed, D. F. 1981. Conflicts with civilization. Pages 509–545 *in* O. C. Wallmo, editor. *Mule and black-tailed deer of North America*. University of Nebraska Press, Lincoln, Nebraska, USA.
- Rheindt, F. E. 2003. The impact of roads on birds: Does song frequency play a role in determining susceptibility to noise pollution? *Journal für Ornithologie* 144:295–306.
- Roedenbeck, I. A., and P. Voser. 2008. Effects of roads on spatial distribution, abundance and mortality of brown hare (*Lepus europaeus*) in Switzerland. *European Journal of Wildlife Research* 54:425–437.
- Romin, L. A., and J. A. Bissonette. 1996. Temporal and spatial distribution of highway mortality of mule deer on newly constructed roads at Jordanelle Reservoir, Utah. *Western North American Naturalist* 56:1–11.
- Rondinini, C., and C. P. Doncaster. 2002. Roads as barriers to movement for hedgehogs. *Functional Ecology* 16:504–509.

- Rost, G. R., and J. A. Bailey. 1979. Distribution of mule deer and elk in relation to roads. *Journal of Wildlife Management* 43:634–641.
- Rowland, M. M., M. J. Wisdom, B. K. Johnson, and M. A. Penninger. 2005. Effects of roads on elk: implications for management in forested ecosystems. Pages 42–52 *in* M. J. Wisdom, editor. *The Starkey Project: a synthesis of long-term studies of elk and mule deer*. Alliance Communications Group, Lawrence, Kansas, USA.
- Russell, C. P. 1932. Seasonal migration of mule deer. *Ecological Monographs* 2:1–46.
- Sawyer, H., M. J. Kauffman, R. M. Nielson, and J. S. Horne. 2009. Identifying and prioritizing ungulate migration routes for landscape-level conservation. *Ecological Applications* 19:2016–2025.
- Sawyer, H., M. J. Kauffman, A. D. Middleton, T. A. Morrison, R. M. Nielson, et al. 2013. A framework for understanding semi-permeable barrier effects on migratory ungulates. *Journal of Applied Ecology* 50:68–78.
- State Farm. 2012. Deer collisions increase, WV #1 again, Arkansas #9 nationally. State Farm Insurance Company. <http://www.statefarm.com/aboutus/_pressreleases/2012/deer-crash-rankings-ar>. Accessed 29 Apr 2013.
- Stewart, K. M., R. T. Bowyer, J. G. Kie, and M. A. Hurley. 2010. Spatial distributions of mule deer and North American elk: resource partitioning in a sage-steppe environment. *The American Midland Naturalist* 163:400–412.
- Taylor, B. D., and R. L. Goldingay. 2010. Roads and wildlife: impacts, mitigation and implications for wildlife management in Australia. *Wildlife Research* 37:320–331.
- Thomas, T. R., and L. R. Irby. 1990. Habitat use and movement patterns by migrating mule deer in Southeastern Idaho. *Northwest Science* 64:19–27.

- Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14:18–30.
- Tull, J. C., and P. R. Krausman. 2007. Habitat use of a fragmented landscape by females in a small population of desert mule deer. *The Southwestern Naturalist* 52:104–109.
- U.S. Census Bureau. 2010. Resident population data. <<http://www.census.gov/2010census/data/>>. Accessed 25 Apr 2013.
- U.S. DOT. 2010. 2010 status of the Nation's highways, bridges, and transit: conditions and performance. United Department of Transportation, Washington, D.C., USA.
- UDOT. 2010. Vehicle miles of travel. Utah Department of Transportation. <<http://www.udot.utah.gov/>>. Accessed 25 Apr 2013.
- West, P. W. 2008. UDOT wildlife and domestic animal accident toolkit. Utah Department of Transportation, Salt Lake City, Utah, USA.
- Wisdom, M. J., N. J. Cimon, B. K. Johnson, E. O. Garton, and J. W. Thomas. 2004. Spatial partitioning by mule deer and elk in relation to traffic. Pages 509–530 *in*. Transactions of the 69th North American Wildlife and Natural Resources Conference. Wildlife Management Institute, Spokane, Washington, USA.

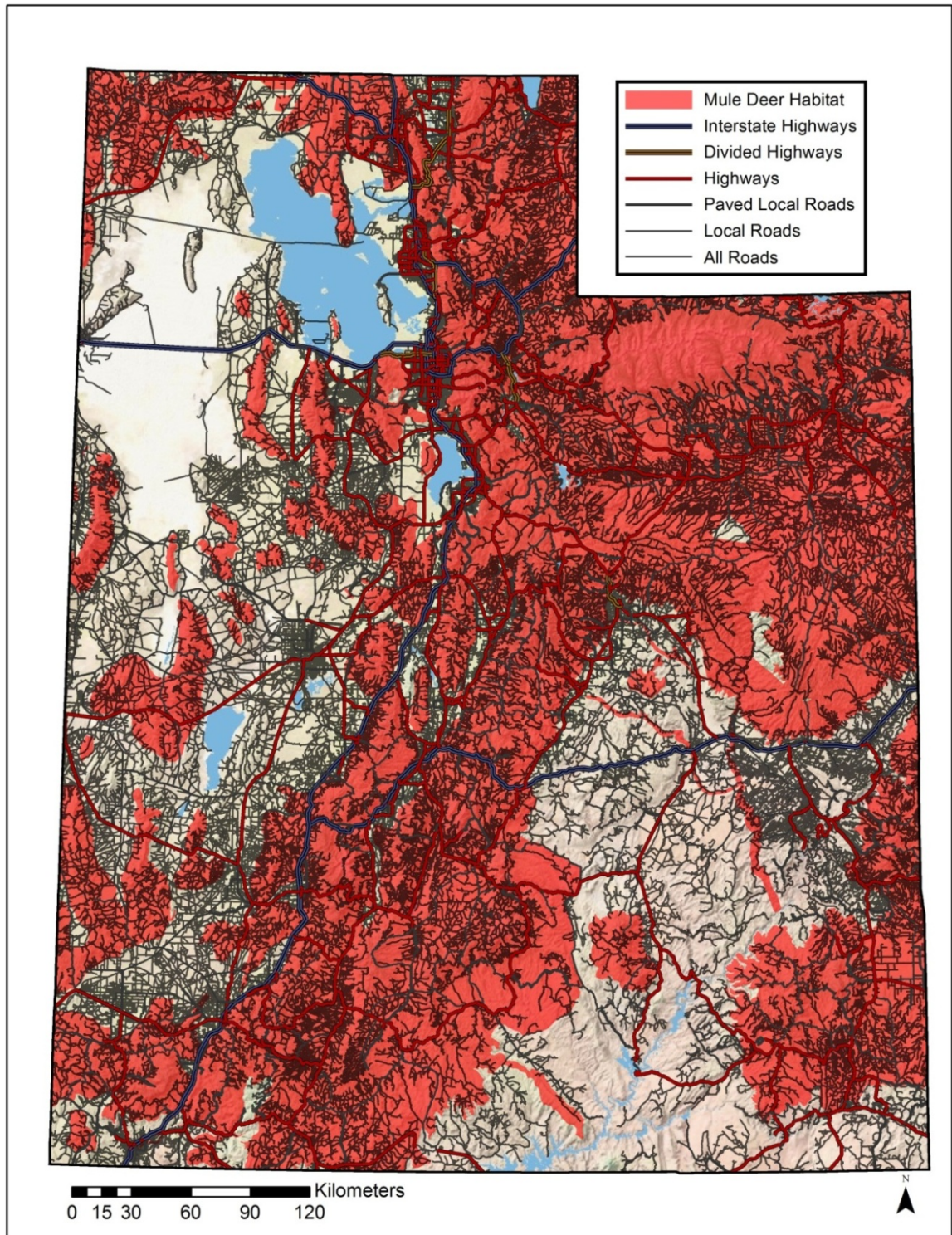


Figure 1.1. The road network in Utah overlaid on mule deer habitat.

CHAPTER 2

HOW MANY DEER ARE REALLY BEING KILLED IN VEHICLE COLLISIONS?

ABSTRACT

Deer-vehicle collisions (DVCs) are a substantial problem throughout much of the developed world. Accurate estimates of DVCs are needed to effectively mitigate the effects of roads and to properly manage deer populations. However, there is great uncertainty associated with most DVC estimates because commonly used DVC data sources are inherently biased and the bias is rarely accounted for in estimates. In this study, I used carcass surveys to estimate the numbers of vehicle collisions involving mule deer (*Odocoileus hemionus*) in Utah. Carcass surveys were conducted using both automobiles and all-terrain vehicles (ATVs), and carcass detection was estimated and accounted for in DVC estimates. I estimated that automobile surveys detected 41 % of mule deer carcasses that were on or near roads. On average there were 24 DVCs a day during the study. The highest DVC rates occurred in winter (37 DVCs/day) and the lowest rates occurred during summer (18 DVCs/day). I estimated that 2-5 % of the mule deer population in Utah was being killed annually in vehicle collisions, which was less than what was being harvested by hunters (7-9 %). Hunting harvest, however, was strongly biased toward male deer, while the majority of deer involved in vehicle collisions were female. Consequently, DVCs that remove a smaller proportion of animals than hunting likely had a stronger influence on population growth. Additionally, I compared DVC data sources (accident reports, insurance claims, and carcass surveys) to provide agencies with insight into the biases associated with using each of these data sources. I found that carcass survey totals were 526 % higher than accident report totals and 196 % higher than insurance claim estimates, which suggests that commonly used DVC data substantially underestimates the problem. Additionally, while I estimated that thousands of deer were being killed annually in DVCs, I observed no change in the long term

trajectory of the mule deer population in Utah, suggesting that DVCs had little effect on mule deer dynamics at that scale.

INTRODUCTION

Deer (Cervidae), which occur throughout much of the world (Geist 1998), appear to be especially vulnerable to vehicle collisions (Mysterud 2004, Huijser et al. 2008, Pérez-Espona et al. 2009). For example, high numbers of deer-vehicle collisions (DVCs) have been reported in Japan, Canada, the United States, and throughout Europe (Bruinderink and Hazebroek 1996, Ng et al. 2008, Noro 2010). In the United States alone, there are ~1-2 million vehicle collisions with large animals each year, most of which involve deer (Conover 2001, Huijser et al. 2008). Reports from Europe indicate that DVCs may exceed 500,000 (Bruinderink and Hazebroek 1996). There is, however, great uncertainty surrounding most DVC estimates, because commonly used DVC data types generally underrepresent the actual number of deer being killed, and the magnitude of the underestimate is usually unknown (Huijser et al. 2007).

While deer species throughout the world range widely in size (11-771 kg) (Scott 1987, Bowyer et al. 2003), many are large enough to cause substantial vehicle damage, human injuries, and human fatalities (Langley et al. 2006). For example, mean damage estimates from DVCs ranged from \$8,388 to \$30,773 (Huijser et al. 2008), and are dependent on the size of the species involved in the accident and value of the automobile. In the United States costs associated with vehicle collisions with large animals, most of which were deer, exceeded \$8 billion annually (Huijser et al. 2008). Human injuries occurred in $\leq 5\%$ of DVCs (Seiler 2004, Bissonette et al. 2008). In the United States human fatalities related to wildlife-vehicle collisions have risen to ~200 each year (Langley et al. 2006), and the loss of each human life has been valued at \$3.3-\$9.1 million (Huijser et al. 2008, Sinha and Braun 2010, Lefler et al. 2011). Consequently, DVCs are a key safety concern for many countries that have large populations of deer.

Deer-vehicle collisions also have the potential to impact deer populations, because the majority of deer (> 90 %) involved in vehicle collisions die as a result of the injuries (Allen and McCullough 1976). For example in Florida, vehicle-related mortality was the leading cause of death for the endangered Key deer (*Odocoileus virginianus clavium*), representing > 50 % of the total mortality (Lopez et al. 2003). High vehicle-related mortality rates, however, do not occur in all deer populations; for instance, Pierce et al. (2012) reported that < 10 % mortality was attributed to vehicle collisions for mule deer (*Odocoileus hemionus*) in California. Because deer typically have high reproductive rates, populations can sustain significant annual mortality (McCullough 1997); consequently, few studies have demonstrated deer population declines as a result of vehicle collisions. As a result, DVCs have been considered more of a public safety issue rather than a threat to the population persistence of most deer populations.

Due to the public safety concerns and economic costs associated with DVCs, transportations agencies sometimes employ mitigation measures to reduce the number of DVCs (Romin and Bissonette 1996a, Sullivan and Messmer 2003) . Mitigation measures include warning signs (Found and Boyce 2011), warning reflectors (Reeve and Anderson 1993), electronic animal detection systems (Huijser and McGowen 2003), exclusionary fencing to prevent wildlife from accessing the road (Clevenger et al. 2001), wildlife crossings (Cramer and Bissonette 2006), and other measures (DeNicola and Williams 2008, Rutberg and Naugle 2008). Though mitigation measures have varying levels of effectiveness (Mastro et al. 2008) , exclusionary fencing combined with wildlife crossings appears to be one the most effective methods for reducing DVCs (McCollister and Van Manen 2010, Sawyer et al. 2012). However, fencing and wildlife crossings are also among the most costly mitigation options. For example, exclusionary fencing costs ~\$100,000 per mile to install (Huijser et al. 2009) and wildlife crossings can cost \$200,000-\$1,800,000 to construct (P. Basting, Personal Communication 2013).

Since DVC mitigation is expensive, transportation agencies are often reluctant to allocate funds to mitigation unless it is perceived to be a substantial problem (Sullivan and Messmer 2003). The perception of the problem is determined in part by the type of DVC data available (e.g., accident reports, insurance claims, or carcass surveys). In the past, accident reports have been used to evaluate the number and locations of DVCs (Sullivan and Messmer 2003, Huijser et al. 2007). Typically, accident reports are filed by public safety officers for vehicle collisions resulting in > \$1,000 in damages (Joyce and Mahoney 2001) or if an injury or death results (Bissonette et al. 2008). Deer-vehicle collision totals from accidents reports are always underestimates, because not all DVCs result in injury, death, or > \$1,000 in damages, and not all are reported by the drivers. The degree to which accident reports underestimate the actual number of DVCs is generally unknown.

In the past decade, some insurance companies began publishing DVC estimates based on claims filed by their customers (State Farm 2012). Insurance claims also underrepresent the problem, because claims are only filed if: 1) there is enough vehicle damage to warrant a claim, and 2) the motorist has comprehensive insurance coverage and is willing to report the accident . The degree to which insurance claims underestimate the total number of DVCs is also largely unknown, but limited evidence suggests that DVC estimates from insurance claims are generally higher than estimates from accident report data (Donaldson and Lafon 2010).

Carcass surveys, which involve observers physically counting deer carcasses on or near roads, are an effective but less commonly used method for estimating DVCs (Huijser et al. 2007). Like other forms of DVC data, carcass surveys are underestimates (Huso 2011), because 1) observers may not locate all carcasses on roadsides during the survey (search efficiency), 2) carcasses may be removed by scavengers prior to the survey (carcass persistence), or 3) injured animals may leave the survey area prior to death (retention). While these factors may be

accounted for in carcass surveys for smaller species (Smallwood and Thelander 2008, Korner-Nievergelt et al. 2011), they have been acknowledged but not accounted for in most estimates of DVCs (Knapp et al. 2007, Donaldson and Lafon 2008, Lao et al. 2012). Because deer carcasses are large and often readily apparent on roads, it has likely been assumed that detection is high and does not substantially bias survey estimates. This assumption, however, has not been verified and needs to be examined. Carcass survey totals (uncorrected for bias) are generally higher than accident report and insurance claim totals (Donaldson and Lafon 2010).

Transportation agencies that invest substantial resources in mitigation need accurate DVC estimates as a foundation for the mitigation process. Additionally, wildlife management agencies need accurate estimates of DVCs to more effectively manage deer populations. Accurate DVC estimates require some estimate of the magnitude of the biases associated with commonly used DVC data (Huijser et al. 2007). The objective of this paper was to provide an unbiased estimate of the number of DVCs in Utah, a state with an abundant mule deer population and a high number of DVCs. To estimate DVCs, I used a combination of carcass survey techniques. To increase the accuracy of my survey estimates, I accounted for search efficiency, carcass persistence, and other factors that influenced DVC estimates. Additionally, I compared carcass survey estimates to accident report and insurance claim estimates across the state, to provide agencies with insight into the biases associated with using each of these data sources.

STUDY AREA

Utah (219,807 km²) is located in the heart of southwestern United States (Fig. 2.1), and is an ecologically diverse region. The topography of the landscape is highly variable (663-4,123 m), and is typified by numerous mountain ranges, valleys, and river canyons (Leydsman McGinty and McGinty 2009). Much of the state is considered semi-arid, receiving 127 to 381 mm of precipitation annually; however, high elevations may receive up to 1473 mm (Gillies and Ramsey

2009). The climate in most of Utah is characterized by hot, dry summers and cold winters, but milder winters generally occur in the southern portions of the state. Utah lies at the intersection of three ecoregions that comprise the majority of the state: Colorado Plateau, Wasatch and Uinta Mountains, and Central Basin and Range (Griffith and Omernik 2009). As a result, Utah is home to wide variety of plant and animal species that are adapted to a diversity of habitats that range from salt desert to alpine tundra. Utah is also inhabited by several deer species that include mule deer, white-tailed deer (*Odocoileus virginianus*), elk (*Cervus elaphus*), and moose (*Alces alces*). Mule deer were the most abundant and widely distributed cervid in Utah during the study; according to Utah Department of Wildlife Resources (UDWR) estimates, there were 293,700 mule deer in 2010 and 286,100 in 2011 (Bernales et al. 2011). Because mule deer were abundant and widely distributed, they were frequently involved in vehicle collisions (Romin and Bissonette 1996b). Utah Department of Transportation (UDOT) accident reports and insurance claims indicated that several thousand deer were being killed in vehicle collisions each year in the state; consequently, deer-vehicle collisions are considerable public safety concern in Utah (West 2008). For example, vehicle-collisions with large vertebrates in Utah, most of which were mule deer, resulted in economic losses (e.g., fatalities, injuries, property damage) of \$7.5 million annually (Bissonette et al. 2008).

In recent years, Utah has experienced high rates of urbanization and human population growth (Leydsman McGinty 2009). According to the latest United States census (U.S. Census Bureau 2010), Utah was the third fastest growing state. The increasing human population concomitantly has increased demand for transportation in the state. As a result, traffic volumes have doubled over the last 30 years (UDOT 2010). Utah's road network consisted of 9,428 km (~5,858 mi) of state routes and ~ 63,985 km (~39,759 mi) of city, county, and other roads (Pope and McEwan 2012). For roads where traffic volumes were measured in Utah, Average Annual

Daily Traffic (AADT) varied between 10 and 252,000 vehicles (median = 5,715) (UDOT 2010). The structure of road sides also varied widely in Utah, with some roadsides being narrow and flat with low vegetation and others being wide and steep with tall vegetation. Additionally, many roads had some form of right-of-way fencing that was designed for livestock (1.2 m), but there were some highways with sections of exclusionary deer fencing (2.4 m). Occasionally roadsides had no fencing.

METHODS

Carcass Surveys

I used a combination of automobile and All-Terrain Vehicle (ATV) carcass surveys to count mule deer carcasses that occurred on and near roads. In Utah, automobile surveys have been conducted systematically since at least 1998 (Bissonette and Rosa 2012). Automobile surveys were done by UDOT contractors who were obligated to drive assigned routes (Fig. 2.1) 2 times per week throughout the year. UDOT contractor routes were selected because they had high numbers of wildlife-vehicle collisions, most of which involved mule deer. Automobile surveys were generally performed by a single person, who acted as driver and observer. Survey automobiles were driven at the posted speed limit. Posted speed limits on contractor routes varied between 16 and 128 kmph (10-80 mph), but on most routes the speed limit was between 88 and 104 kmph (55-65 mph). If the road had multiple traffic lanes, the survey automobile was driven in the slow lane, nearest to the shoulder of the road. Undivided roads were surveyed in only one direction, while divided roads with a median were surveyed in both directions. During surveys, UDOT contractors were required to remove all carcasses that were detected on the road surface, the median, and the road shoulder out to the reflective highway markers. They kept detailed records of the species removed and their locations. Location data were recorded as both the

highway number and nearest mile marker, and as GPS coordinates recorded with a Garmin eTrex Legend H unit (Garmin, Olathe, Kansas, USA).

Automobile surveys generally do not detect all carcasses (Slater 2002), so technicians also surveyed sections of UDOT contractor routes using ATVs to identify undetected carcasses. Although ATVs are commonly used in wildlife research (Lesage et al. 2000, Mooring et al. 2004), using ATVs for carcass surveys is apparently a novel technique, as I found no references to their use in detecting carcasses. Surveys were conducted using ATVs because they were more efficient than walking surveys and allowed technicians to sample more and longer transects, while at the same time enabling them to carefully search roadsides and detect carcass by both sight and smell. ATV survey transects were delineated by dividing all UDOT contractor routes into 4.8 km (3 mi) segments using ArcGIS 10.1 (ESRI, Redlands, CA). I then overlaid survey transects on carcass locations that were reported by UDOT contractors in 2009 to get the number of reported deer carcasses for each transect. Because DVCs in Utah have a clustered distribution along roads (Kassar and Bissonette 2005), I used a proportional sampling design to select survey transects. Using proportional sampling, segments with higher numbers of reported carcasses had a higher probability of being included in the sample. To account for seasonal changes in deer distributions and movement patterns, I also stratified my sample by season (spring = April 1-May 30, summer = June 1–September 30, fall = October 1-December 15, winter = December 16-March 31). Transects were surveyed once every 14 days during each season.

All ATV surveys were conducted by trained technicians employed by Utah State University (USU). During an ATV survey, the technician functioned as both driver and observer. ATVs were driven at 8- 16 kmph (5-10 mph) on both shoulders of the road transect and in the median of divided roads. Technicians recorded carcass locations using a Garmin eTrex Legend H GPS unit. All carcasses detected during ATV surveys were marked with an orange, serially

numbered marker (11” cable tie, item number = 11-50-3-SN, American Sales and Distributing, Santa Rosa, CA, USA) that was placed around the hind leg of the carcass. Carcasses were marked to help insure that they were not double counted by either USU technicians or UDOT contractors. Additionally, deer carcasses from vehicle-collisions that occurred prior to the season of interest were marked and excluded from the analysis. Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

To account for the biases inherent in ATV surveys, I estimated search efficiency, carcass persistence, and retention. Search efficiency, the ability of an observer to detect a carcass given it is present in the survey area (Huso 2011), was estimated directly by placing deer decoys in known locations within randomly selected transects. Decoys commonly have been used to estimate detection of wildlife (Smith et al. 1995, Ward et al. 2006, Cooley et al. 2008). Within transects, decoys were placed at random locations in the median or on roadsides of transects. Due to safety concerns, decoys were never placed in the traffic lanes. The number of decoys placed in each transect was a random number from 5-10, so the designated observer could not anticipate the number of decoys available to be detected. Search efficiency surveys were also stratified by season, but no surveys were conducted during winter. Decoys were not placed in winter because most roadsides were snow covered for much of the season and decoys could not be positioned without leaving obvious visual cues as to their locations (i.e., foot tracks).

Two types of decoys were used to estimate search efficiency: one to represent adult deer and one to represent juvenile deer. For adult deer, I used the Flambeau grazing doe decoy (model number = 5967GD, Flambeau, Inc., Middlefield, Ohio, USA). Because these decoys were modeled after white-tailed deer, I modified decoy coloring to better represent the coloration of mule deer in my study area. I also cut decoys in half along the sagittal plane. This modification was done so decoys would more accurately represent the deflated nature of most deer carcasses

(Fig. 2.2). The dimensions of the modified adult decoys were 125 cm from nose to tail, 93 cm from feet to the top of back, and 17 cm deep. For juvenile deer, I used Edge fawn predator decoys (model number = 21-51208-1, Edge by Expedite, Hudson, Wisconsin, USA). I also modified the coloration of these decoys. The dimensions of juvenile decoys were 73 cm nose to tail, 31 cm from feet to top of back, and 13 cm deep.

To estimate search efficiency, I fit generalized linear models in R 2.14.2 (R Development Core Team 2012), where the response was binary (1 = decoy detected, 0 = decoy undetected). To test the assumption that detection was similar across seasons, observers, and stage class (adult or juvenile), I fit models with those covariates and compared them to the null model using AIC (Akaike 1973), with a correction for small sample sizes (Burnham and Anderson 2002).

I estimated carcass persistence by placing fresh mule deer carcasses (≤ 2 days old) at random locations along contractor routes. Carcass persistence was also stratified by season and measured for all seasons except winter. Deer carcasses were placed in clusters of 3. In each cluster, carcasses were placed 5, 10, and 30 m from the surface of the road to determine if distance affected carcass persistence. Carcasses were marked with orange and white marks to indicate to UDOT contractors that the carcasses should not be removed from roadsides during the study. Deer carcasses were visually inspected each week to determine the fate of the carcasses. A carcass was considered present on the roadside if it was identifiable as a deer carcass, even if it had been moved a short distance by scavengers. A carcass was considered absent if it was missing and could not be located within 100 m of its original location. Carcass persistence was estimated using known-fate models in program Mark 6.1 (White and Burnham 1999). To test the assumption that carcass persistence was similar across seasons, distances from the road, and stage classes, I fit models with those covariates and compared them using the same methods that were used for search efficiency.

Not all deer that die from vehicle-collision injuries remain within the carcass survey area, and because no standard term exists for this phenomenon, I referred to it as retention. I specifically defined retention as the proportion of mortally injured animals that remain in the survey area. Retention of deer carcasses is likely influenced by right-of-way fencing, with the highest retention rates occurring in areas with exclusionary fencing and the lowest rates occurring in areas with no fencing. Even right-of-way fencing designed for livestock may prevent injured deer from leaving the right-of-way in some instances. Retention, however, can be difficult to estimate; consequently there is almost no information available on this factor. Nevertheless, it can be an important source of bias for carcass surveys (Huso 2011).

To estimate retention, I used cause-specific mortality data that were collected for a mule deer population in northern Utah from 2002 to 2006 (Peterson and Messmer 2011). I used this dataset because it was a relatively large sample of individuals and the population experienced high levels of vehicle related mortality, which allowed us to detect the somewhat rare event of a deer being involved in vehicle collision but dying a considerable distance from the road. The dataset consisted of adult female mule deer that were captured using clover traps and instrumented with VHF tracking collars with mortality sensors. Deer survival status was monitored 2-3 times per week. When mortalities were detected, carcasses were located and examined within 48 hours to assign a cause of death. Additionally, the distance of carcasses to the nearest major road was recorded. I estimated retention as the proportion of vehicle collision mortalities that were located within 75 m of major roads. I used the 75 m cut off because in this area there was no right-of-way fencing in much of the study area and > 95 % of carcasses detected with ATV surveys were within 75 m from the road, indicating that carcasses located greater than that distance would have a low probability of being detected by my survey techniques.

Coverage

The intended target population for this study was all DVCs that occurred throughout Utah. Because UDOT contractor routes constituted only a fraction of the roads in the state, totals from contractor routes underestimated the total number of DVCs that occurred in the state. To account for some of this coverage bias and expand my inference to the all UDOT administered roads within the state, I examined accident report data that were compiled by Kassir and Bissonette (2005). From these data, I calculated the proportion of accident reports that occurred on roads that were surveyed by UDOT contractors. This gave us an estimate of the UDOT contractor coverage of DVCs on UDOT administered routes, and provided a meaningful adjustment for my estimates. However, I had no way to account for DVCs that occurred on city streets and other roads that were not administered by UDOT, so my estimate is still biased low.

DVC Estimate

I estimated the total number of DVCs in my study area by combining automobile and ATV carcass survey estimates. The automobile survey estimate I used was the number of mule deer carcasses reported by UDOT contractors with an adjustment for retention. The ATV survey total that I used was generated with the wildlife fatality estimator (Equation 1) developed by Huso (2011). Using this model, the estimated number of carcasses \hat{F} is essentially a function of the number of carcasses observed c , carcass persistence \hat{r} , search efficiency \hat{p} , and the effective search interval \hat{v} . The effective search interval \hat{v} is a derived parameter that helps account for bias created by circumstances where carcasses persistence is short relative to the survey intervals. A description of all model parameters is provided in Table 2.1. The model also includes a parameter K that allows groupings of carcasses to have different detection probabilities. I assumed all carcasses had similar detection rates and did not use this parameter. The parameter π is the

probability that a transect was included in the sample and it allowed me to incorporate the proportional sampling design which had unequal selection probabilities. The π parameter was also multiplied by the retention estimate to account for injured deer that left the survey area. I generated 95% confidence intervals for the estimate using the bootstrap function in the boot package in R.

Equation 1:

$$\hat{F} = \sum_{i=1}^n \frac{1}{\pi_i} \sum_{j=1}^{S_i} \sum_{k=1}^{K_{ij}} \frac{c_{ijk}}{\hat{r}_{ijk} \hat{p}_{ijk} \hat{v}_{ijk}}$$

Comparison of DVC Data Types

I compared carcass survey estimates with accident report and insurance claim totals. Accident report data were collected and maintained by UDOT (West 2008). In recent years, UDOT has restricted access to this information, and consequently I did not have accident report data for the years of the study. Accident report data in Utah, however, varied little from year to year, so I used a previously published report to obtain accident report totals for 1992 to 2005 (West 2008). From this information, I calculated a mean value and used that for my comparison. Accident report totals included accidents involving deer, elk, and moose. Insurance claims totals were obtained from estimates published by State Farm Insurance (State Farm 2012). The published insurance claim estimates were derived from the number of claims filed that involved deer, elk, and moose. Because State Farm services only a fraction of the insurance customers in Utah, estimates of DVCs from insurance claims were adjusted for the company's market share.

Accident report and insurance claim estimates included not only mule deer but elk and moose, so I included all reported mule deer, elk, and moose carcasses in my survey estimate for

this comparison. Additionally, I adjusted carcass totals by the detection rate determined for mule deer carcasses.

RESULTS

Carcass Surveys

From 1 July 2010 to 15 December 2011, UDOT contractors conducted ~148 driving surveys and drove ~422,400 km. During that time, they reported 5,002 mule deer carcasses (Table 2.2). Driving survey totals varied by season ($\chi^2 = 283, p < 0.01$) with the highest total reported in winter 2010 (1,428 carcasses) and the lowest reported in spring 2011 (473 carcasses). Mule deer represented 92 % of all wildlife carcasses that were reported by UDOT contractors.

During the same period, a total of 1,350 ATV surveys were conducted on 225 road transects. The mean number of transects surveyed per season was 38 ($SD = 2.9$). In total, 577 mule deer carcasses were detected during ATV surveys. Of those carcasses, 62 % were also removed and reported by UDOT contractors. Using the wildlife fatality estimator, I estimated that 5,527 carcasses were unreported by UDOT contractors during the study (Table 2.2), meaning that automobile surveys detected 41 % of mule deer that were killed in vehicle collisions. ATV survey estimates also varied seasonally ($\chi^2 = 443, p < 0.01$), with the highest total in winter 2010 (1,685 carcasses) and the lowest in fall 2011 (503 carcasses).

Search efficiency surveys for deer decoys were performed from 1 April 2012 to 15 December 2012, which encompassed 3 seasons (spring, summer, and fall). Technicians surveyed 10 transects per season and mean number of decoys placed per season was 75. Overall search efficiency for deer decoys was 0.77 ($SE = 0.03, 95\% CI = 0.72-0.83$). When I compared competing models of search efficiency, I found little support for models that contained covariates for observer, season, or stage class (Table 2.3).

Carcass persistence monitoring was conducted during the same period. Seventy-eight deer carcasses were monitored during the study period. The mean number of carcasses monitored per season was 26. Overall weekly carcass persistence was 0.99 ($SE < 0.01$, 95 % $CI = 0.99-1.00$). When I modeled carcass persistence for covariate effects, I did not detect any seasonal, distance, or stage class effects (Table 2.4).

Retention was estimated by monitoring the survival of 100 mule deer does in northern Utah. During the study, 20 % ($n = 20$) of the research animals were determined to have died from injuries that resulted from vehicle collisions. Of the 20 deer that were killed in vehicle collisions, 15 were found < 75 m from the nearest major road. From these data, I estimated that retention was 0.75 ($SE = 0.10$, 95 % $CI = 0.56-0.94$).

Coverage

To expand my inference from UDOT contractor's routes to all highways throughout the state, I estimated UDOT contractor coverage of DVCs from accident report data. From 1992 to 2002, Kassar and Bissonette (2005) reported that there were 18,639 vehicle accident reports on UDOT administered roads that involved mule deer. Of those reported accidents involving mule deer, 17,039 occurred on routes that were patrolled by UDOT contractors. From this information, I estimated contractor coverage of DVCs on UDOT administered roads to be 91 %.

DVC Estimate

By combining automobile and ATV survey estimates and adjusting for coverage bias, I estimated that there were 13,344 mule deer killed in vehicle collisions during the study, and that 9,579 mule deer were killed during the first year (1 July 2010 - 30 June 2011) (Table 2.2). I also used DVC estimates to derive vehicle collision rates. On average, there were 24 ($n = 6$, $SD = 7.2$) DVCs each day. Vehicle collision rates varied seasonally ($\chi^2 = 774$, $p < 0.01$), with the highest

vehicle collisions rates occurring in winter (37 DVCs/day), intermediate rates occurring in spring (23 DVCs/day) and fall (24 DVCs/day), and the lowest rates occurring during summer (18 DVCs/day).

Comparison of DVC Data Types

From 1992 to 2005, the mean number of accidents reported per year involving mule deer, elk, and moose was 2,178 ($SD = 150$, range = 2,035-2,625). From 2008 to 2012, the mean number of estimated insurance claims per year involving the same species was 5,841 ($SD = 361$, range = 5,384-6,190). The mean number of estimated carcasses for those species was 11,458 ($SD = 3,836$, range = 7,373-15,371) during 2008 to 2012. Annual estimates of DVCs from carcass surveys were 526 % higher than accident report totals and 196 % higher than insurance claim estimates. Additionally, annual variability of carcass surveys, as measured by the standard deviation, was 2,557 % higher than accident reports and 1060 % higher than insurance claims. Using the assumption that 92 % of DVCs involve mule deer, I estimated from carcass surveys that 2 to 5 % (8,354-13,987 mule deer) of the mule deer population was killed annually in vehicle collisions from 2008-2012 on UDOT administered roads.

DISCUSSION

My purpose for conducting this study was to provide agencies with an accurate DVC estimates so mitigation can be effectively implemented to benefit both drivers and deer. My estimate of DVCs was generated from both automobile and ATV carcass surveys. Automobile surveys were an efficient method for searching large areas and > 5,000 deer carcasses were reported during the study; but without accounting for detection, automobile surveys would have underestimated the number of DVCs by at least one half. The significance of detection has long been recognized by researchers investigating wildlife mortality associated with wind turbines

(Osborn et al. 2000), because when detection is not accounted for, estimates can be substantially biased (Huso 2011). My results indicate that carcass detection plays a major role in DVC estimates.

The detection rate I report for automobile surveys was low, but this may not necessarily be the case for every study that uses automobile surveys to detect deer carcasses. For instance in my study, driving surveys were performed by contractors who were attempting to cover large areas rapidly, and they were not necessarily concerned with finding every deer carcass possible. The contractors' primary objective was to clear the roadway of carcasses. Detection rates certainly could have been improved by having contractors drive slower and by having a second observer in the vehicle. This, however, would have not resulted in a detection rate that approached 100 %, because many of the highways in Utah have wide roadsides with tall brush and trees, which can make detecting some carcasses difficult to nearly impossible. One conceivable circumstance where detection would be high would be on narrow roadsides (< 10 m) that were flat and devoid of vegetation. This situation did occur in my study area, but was relatively uncommon.

Detection rates of deer carcasses are a function of search efficiency, carcass persistence, and retention. Search efficiency for ATV surveys during my study was high (72 %), but not high enough to be inconsequential. When I began the study, I anticipated that search efficiency for ATV surveys would likely be > 90 %, but factors such as topography and vegetation limited the effectiveness of ATVs. For instance, it was difficult to search steep roadsides with tall brush and trees, because those factors limited ATV mobility and also the distance observers could see. ATV surveys, however, did have advantages over driving surveys, because 1) the observer could search more of the roadside, 2) the vehicle moved slower allowing the observer to see more of the surrounding area, and 3) carcasses could be detected by smell. Additionally, I found that search

efficiency was relatively constant between seasons and observers, suggesting the technique produced repeatable results. However, I did not estimate search efficiency during winter, which could have been different than the other seasons that were relatively free of snow.

My estimate of carcass persistence indicated that this factor played a minor role in detection of deer carcasses. Most carcasses remained undisturbed or had only small amounts removed by scavengers. However, carcasses were only monitored during the warmer seasons of the year when carcasses tended to become rancid quickly. This fact may have made carcasses less attractive to scavengers such as coyotes and cougars that are capable of removing whole carcasses. During winter when cold temperatures preserve carcasses and food sources are scarce for most scavengers, it is possible that carcass persistence rates may be lower.

It is also important to note that my estimate of carcass persistence referred only to carcasses on roadsides. I was not able to estimate persistence of deer carcasses that remained in the traffic lanes. In Utah, deer carcasses that are blocking traffic lanes are usually moved to the shoulder of the road relatively quickly by public safety officers, maintenance crews, or other drivers. However, occasionally carcasses remain in the traffic lanes and on some high volume roads they are quickly destroyed by vehicles driving over them. I could not estimate the persistence of deer carcass in traffic lanes experimentally because of safety concerns. Nevertheless, a percentage of deer carcasses are destroyed by vehicle traffic before they can be reported which suggests that actual carcass persistence can be lower than the estimate I reported for roadside persistence.

Retention was an important factor influencing detection of deer carcasses in my study, and my estimate indicated that up to a quarter of deer that are involved in vehicle collision were able to move considerable distances from the road before they died. This result, however, was obtained from an area that had few fences to restrict the movements of injured deer, but roadside

fencing was common on many of the roads I surveyed throughout the state. If I had been able to quantify retention across the state, I likely would have found on average it was higher than 75 % rate I observed in northern Utah because of the presence of roadside fencing. The only comparable estimate of retention I could find was from Colorado, where Myers (1969) estimated that 15 % mule deer carcasses were far enough from the road that they could not be found during surveys, but he did not indicate how this estimate was generated. This is an area that still needs considerable research.

In my study, carcass survey estimates were higher than both accident report totals and insurance claim estimates. This result agrees with previously published studies on the subject (Knapp et al. 2007, Donaldson and Lafon 2010, Lao et al. 2012). The degree to which carcass survey estimates differed from accident report totals was similar between studies. In my study, I found that carcass survey estimates were 5.3 times higher than accident report totals. In Iowa, Knapp et al. (2007) reported that carcass surveys estimates were 3.8 to 8.6 times greater accident report totals. Additionally, in Virginia Donaldson and Lafon (2010) found that carcass surveys were 8.6 to 9.3 times higher accident report totals. Lao et al. (2012) reported an analogous finding where carcass surveys totals were up to ~8 times higher than accident report totals for highways in the state of Washington. These studies strongly suggest that accident report data severely underestimates DVCs, resulting in discrepancy between how agencies perceive the DVC problem and the reality of the problem.

Accident reports and insurance claims showed little annual variability, but carcass survey estimates were highly variable. There are ecological reasons as to why DVCs should be variable among years. Mule deer population dynamics, especially in temperate climates, can be highly variable (Mckinney 2003). For instance in Utah, a severe winter in 1984 reduced many mule deer populations 50-70 % (Austin 2010). Fewer mule deer concomitantly leads to fewer DVCs

(Lehnert et al. 1998), which has been also demonstrated experimentally for white-tailed deer (DeNicola and Williams 2008). Additionally, exposure of deer to roads also varies annually. During winters with warm temperatures and light snowfalls, deer have more available habitat and consequently are not restricted to areas close to roads. Conversely, cold winters with high snow accumulations may force deer into habitats near high volume roads, increasing DVC rates. These factors should cause DVC estimates to be variable between years, but interestingly only carcass surveys produced highly variable estimates.

Variability in carcass survey estimates is not exclusively due to ecological factors. Survey effort could have played an important role. For instance, It is possible that contractors increased survey effort during the study, because they aware that their performance was being evaluated by researchers. Whether this actually occurred was unknown, but seems likely and certainly could have contributed to some of the annual variation that was observed in carcass survey estimates.

I observed strong seasonal patterns in DVCs rates. Seasonality is a common finding for DVCs, and the pattern that is typically observed, at least for white-tailed deer, is high DVC rates in spring and fall, and lower rates in summer and winter (Puglisi et al. 1974, Allen and McCullough 1976). During my study, I observed that DVC rates were elevated in spring and fall over summer levels, but the highest DVC rates occurred in winter. This pattern can likely be attributed to seasonal movement patterns of deer in Utah. In my study area, many deer populations occupy high elevation summer ranges that are generally farther from high volume roads that are more dangerous for deer. However, DVC rates likely increased in fall and spring because during that time deer were transitioning between summer and winter ranges, and they crossed roads that intersected their migratory paths. During winter deer typically occupied low

elevation ranges that were bisected or adjacent to high volume roads, which possibly contributed to the higher DVCs rates that were observed.

I estimated from carcass surveys that DVCs removed a small percentage (2-5 %) of the mule deer population in Utah, which was about half of what was being harvested by hunters each year (7-9 %). Hunter harvest, however, was strongly biased towards male deer during my study, with only 6-12 % of deer harvested being female (Bernales et al. 2011). Because males generally play a small role in the population dynamics of deer (Gaillard et al. 2000), hunter harvest has limited impact on population growth. Deer-vehicle collisions in Utah, however, involve a high percentage of female deer (> 50 %), which are very important to deer population growth (Romin and Bissonette 1996b). This suggests that while more deer are killed by hunters than in vehicle collisions, collisions are likely a more important factor in determining population growth because of the high percentage of females that are removed.

While there is potential for DVCs to impact mule deer populations at the statewide scale extent, the mule deer population in Utah has been relatively stable for the past 20 years (Bernales et al. 2011), indicating that vehicle-collisions are not substantially impacting the long-term population dynamics. However deer herds within the state experience different levels of vehicle-related mortality and localized populations may be significantly impacted by vehicle collisions. For instance, Lehnert et al. (1998) found that vehicle-related mortality was 50 % additive for one deer herd in central Utah. Additionally, Peterson and Messmer (2011) observed lower than average survival rates for female mule deer in northern Utah in a population with high vehicle-related mortality rates. These considerations suggest that defining DVCs by management unit would be valuable.

It also interesting to note that the percentage of deer killed in vehicle collisions was comparable to the percentage of deer that are killed by predators. For instance in southeastern

Idaho, Laundre et al. (2006) estimated that cougars (*Puma concolor*) killed 2-6 % of the mule deer population annually. Additional studies have reported cougars removing 3-20 % of a mule deer population each year (Shaw 1980, Anderson et al. 1992, Murphy 1998). Cougar predation and DVCs also have similar effects on mule deer demographic groups. For instance in Central Utah, Mitchell (2013) reported that 45-63 % of mule deer killed by cougars were female. Given the similarities between DVCs and cougar predation, it may be beneficial, at least in Utah, to view DVC effects as equivalent to another predator in the ecosystem.

My estimate of DVCs in Utah represents one of the first attempts to account for detection probabilities in deer carcass surveys. The results of the study underscore how important detection can be in carcass surveys, even for large animals such as deer. Detection has rarely been accounted for in deer carcass surveys suggesting that search efficiency, carcass persistence (both on roads and roadsides), and retention need considerable attention in future research.

MANAGEMENT IMPLICATIONS

Deer-vehicle collisions are a major public safety concern. To address the problem effectively, accurate DVC estimates are needed. However, DVC source data vary considerably in their accuracy. I recommend using carcass surveys whenever possible to estimate DVCs, but accident reports and insurance claim estimates may be the only reasonable option for large scales. If carcass surveys are used, accounting for detection probabilities in DVC estimates is important. If agencies use accident report data for mitigation, I recommend that accident report totals be increased by at least 300 %, which will still provide a very conservative estimate of DVCs. Additionally, while I estimated that thousands of deer were being killed annually in DVCs, I observed little change in the long term trajectory of the mule deer population in Utah. However at smaller spatial extents (e.g., hunt management units), deer populations may still be negatively impacted by DVCs.

LITERATURE CITED

- Akaike, H. 1973. Maximum likelihood identification of Gaussian autoregressive moving average models. *Biometrika* 60:255–265.
- Allen, R. E., and D. R. McCullough. 1976. Deer-car accidents in southern Michigan. *Journal of Wildlife Management* 40:317–325.
- Anderson, A. E., D. C. Bowden, and D. M. Kattner. 1992. The puma on Uncompahgre Plateau, Colorado. Colorado Division of Wildlife, Fort Collins, Colorado, USA
- Austin, D. D. 2010. Mule deer: a handbook for Utah hunters and landowners. Utah State University Press, Logan, Utah, USA.
- Bernales, H. H., K. R. Hersey, and A. Aoude. 2011. Utah big game annual report 2011. Utah Division of Wildlife Resources, Salt Lake City, Utah, USA.
- Bissonette, J. A., C. A. Kassar, and J. C. Cook. 2008. Assessment of costs associated with deer-vehicle collisions: human death and injury, vehicle damage, and deer loss. *Human-Wildlife Conflicts* 2:17–27.
- Bissonette, J. A., and S. Rosa. 2012. An evaluation of a mitigation strategy for deer-vehicle collisions. *Wildlife Biology* 18:414–423.
- Bowyer, R., V. Van Ballenberghe, and J. Kie. 2003. Moose: *Alces alces*. Pages 931–964 *in* G. Feldhamer, B. Thompson, and J. Chapman, editors. *Wild mammals of North America: biology, management and conservation*. John Hopkins University Press, Baltimore, Maryland, USA.
- Bruinderink, G. W. T. A., and E. Hazebroek. 1996. Ungulate traffic collisions in Europe. *Conservation Biology* 10:1059–1067.
- Burnham, K. P., and D. R. Anderson. 2002. Model selection and multi-model inference: a practical information-theoretic approach. Springer, New York, New York, USA.

- Clevenger, A. P., B. Chruszcz, and K. E. Gunson. 2001. Highway mitigation fencing reduces wildlife-vehicle collisions. *Wildlife Society Bulletin* 29:646–653.
- Conover, M. R. 2001. *Resolving human-wildlife conflicts: the science of wildlife damage management*. CRC Press, Boca Raton, Florida, USA.
- Cooley, H. S., H. S. Robinson, R. B. Wielgus, and C. S. Lambert. 2008. Cougar prey selection in a white-tailed deer and mule deer community. *Journal of Wildlife Management* 72:99–106.
- Cramer, P., and J. Bissonette. 2006. *Wildlife crossings in North America*. Transportation Research Board. <http://digitalcommons.usu.edu/wild_facpub/1206>. Accessed 15 Apr 2013.
- DeNicola, A. J., and S. C. Williams. 2008. Sharpshooting suburban white-tailed deer reduces deer-vehicle collisions. *Human-Wildlife Interactions* 2:28–33.
- Donaldson, B. M., and N. W. Lafon. 2008. Testing an integrated PDA-GPS system to collect standardized animal carcass removal data. Virginia Transportation Research Council, Charlottesville, Virginia. <<http://trid.trb.org/view.aspx?id=850379>>. Accessed 29 Apr 2013.
- Donaldson, B., and N. Lafon. 2010. Personal digital assistants to collect data on animal carcass removal from roadways. *Transportation Research Record: Journal of the Transportation Research Board* 2147:18–24.
- Found, R., and M. S. Boyce. 2011. Warning signs mitigate deer–vehicle collisions in an urban area. *Wildlife Society Bulletin* 35:291–295.
- Gaillard, J.-M., M. Festa-Bianchet, N. G. Yoccoz, A. Loison, and C. Toigo. 2000. Temporal variation in fitness components and population dynamics of large herbivores. *Annual Review of Ecology and Systematics* 31:367–393.

- Geist, V. 1998. *Deer of the world: their evolution, behaviour and ecology*. stackpole books, Mechanicsburg, Pennsylvania, USA.
- Gillies, R. R., and R. D. Ramsey. 2009. Climate of Utah. Pages 39–45 *in* R. E. Banner, B. D. Baldwin, and E. I. Leydsman McGinty, editors. *Rangelands resources of Utah*. Utah State University Cooperative Extension Service, Logan, Utah, USA.
- Griffith, G. E., and J. M. Omernik. 2009. Ecoregions of Utah (EPA). *Encyclopedia of Earth*. Environmental Information Coalition, Washington, D.C., USA.
<[http://www.eoearth.org/article/Ecoregions_of_Utah_\(EPA\)](http://www.eoearth.org/article/Ecoregions_of_Utah_(EPA))>. Accessed 11 May 2013.
- Huijser, M. P., and P. T. McGowen. 2003. Overview of animal detection and animal warning systems in North America and Europe. Pages 368–382 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. *Proceedings of the International Conference on Ecology and Transportation*. Center for Transportation and the Environment, Raleigh, North Carolina, USA.
- Huijser, M. P., M. E. Wagner, A. Hardy, A. P. Clevenger, and J. A. Fuller. 2007. Animal-vehicle collision data collection throughout the United States and Canada. *Transportation Research Board*, Washington, D.C., USA.
- Huijser, M. P., P. T. McGowen, J. Fuller, A. Hardy, and A. Kociolek. 2008. *Wildlife-vehicle collision reduction study: report to Congress*. Western Transportation Institute, Bozeman, Montana, USA.
- Huijser, M. P., J. W. Duffield, A. P. Clevenger, R. J. Ament, and P. T. McGowen. 2009. Cost–benefit analyses of mitigation measures aimed at reducing collisions with large ungulates in the United States and Canada: a decision support tool. *Ecology and Society* 14:15.
- Huso, M. M. P. 2011. An estimator of wildlife fatality from observed carcasses. *Environmetrics* 22:318–329.

- Joyce, T. L., and S. P. Mahoney. 2001. Spatial and temporal distributions of moose-vehicle collisions in Newfoundland. *Wildlife Society Bulletin* 29:281–291.
- Kassar, C. A., and J. A. Bissonette. 2005. Deer-vehicle crash hotspots in Utah: data for effective mitigation. Utah State University, Logan, Utah, USA.
- Knapp, K., C. Lyon, A. Witte, and C. Kienert. 2007. Crash or carcass data: critical definition and evaluation choice. *Transportation Research Record: Journal of the Transportation Research Board* 2019:189–196.
- Korner-Nievergelt, F., P. Korner-Nievergelt, O. Behr, I. Niermann, R. Brinkmann, and B. Hellriegel. 2011. A new method to determine bird and bat fatality at wind energy turbines from carcass searches. *Wildlife Biology* 17:350–363.
- Langley, R. L., S. A. Higgins, and K. B. Herrin. 2006. Risk factors associated with fatal animal-vehicle collisions in the United States, 1995–2004. *Wilderness & Environmental Medicine* 17:229–239.
- Lao, Y., Y. Wu, Y. Wang, and K. McAllister. 2012. Fuzzy logic-based mapping algorithm for improving animal-vehicle collision data. *Journal of Transportation Engineering* 138:520–526.
- Laundré, J. W., L. Hernández, and S. G. Clark. 2006. Impact of puma predation on the decline and recovery of a mule deer population in southeastern Idaho. *Canadian Journal of Zoology* 84:1555–1565.
- Lefler, N., R. Fiedler, H. McGee, R. Pollack, and J. Miller. 2011. Market analysis of collecting fundamental roadway data elements to support the highway improvement program. United States Department of Transportation, Federal Highway Administration, Washington, D.C., USA.

- Lehnert, M. E., J. A. Bissonette, and J. W. Haefner. 1998. Deer (Cervidae) highway mortality: using models to tailor mitigative efforts. *Gibier Faune Sauvage, Game Wildlife* 15:835–841.
- Lesage, L., M. Crête, J. Huot, A. Dumont, and J.-P. Ouellet. 2000. Seasonal home range size and philopatry in two northern white-tailed deer populations. *Canadian Journal of Zoology* 78:1930–1940.
- Leydsman McGinty, E. I., and C. M. McGinty. 2009. Physiography of Utah. Pages 24–28 *in* R. E. Banner, B. D. Baldwin, and E. I. Leydsman McGinty, editors. *Rangelands resources of Utah*. Utah State University Cooperative Extension Service, Logan, Utah, USA.
- Leydsman McGinty, E. I. 2009. Urbanization in Utah. Pages 153–156 *in* R. E. Banner, B. D. Baldwin, and E. I. Leydsman McGinty, editors. *Rangelands resources of Utah*. Utah State University Cooperative Extension Service, Logan, Utah, USA.
- Lopez, R. R., M. E. P. Vieira, N. J. Silvy, P. A. Frank, S. W. Whisenant, and D. A. Jones. 2003. Survival, mortality, and life expectancy of Florida key deer. *Journal of Wildlife Management* 67:34–45.
- Mastro, L., M. Conover, and S. N. Frey. 2008. Deer–vehicle collision prevention techniques. *Human–Wildlife Interactions* 2:80–92.
- McCollister, M. F., and F. T. Van Manen. 2010. Effectiveness of wildlife underpasses and fencing to reduce wildlife-vehicle collisions. *Journal of Wildlife Management* 74:1722–1731.
- McCullough, D. R. 1997. Irruptive behavior in ungulates. Pages 69–98 *in* W. J. McShea, H. B. Underwood, and J. H. Rappole, editors. *The science of overabundance: deer ecology and population management*. The Smithsonian Institution Press, Washington, D.C., USA.

- Mckinney, T. 2003. Precipitation, weather, and mule deer. Pages 219–238 in J. C. deVos, M. R. Conover, and N. E. Headrick, editors. Mule deer conservation: issues and management. Jack H. Berryman Institute Press, Logan, Utah, USA.
- Mitchell, D. 2013. Cougar predation behavior in north-central Utah. Utah State University, Logan, Utah. <<http://digitalcommons.usu.edu/etd/1539>>. Accessed 25 Jun 2013.
- Mooring, M. S., T. A. Fitzpatrick, T. T. Nishihira, and D. D. Reisig. 2004. Vigilance, predation risk, and the Allee effect in desert bighorn sheep. *Journal of Wildlife Management* 68:519–532.
- Murphy, K. M. 1998. The ecology of the cougar (*Puma concolor*) in the Northern Yellowstone ecosystem: interactions with prey, bears, and humans. Dissertation, University of Idaho, Moscow, Idaho, USA.
- Myers, G. T. 1969. Deer-auto accidents: serious business. *Colorado Outdoors* 18:38–40.
- Mysterud, A. 2004. Temporal variation in the number of car-killed red deer *Cervus elaphus* in Norway. *Wildlife Biology* 10:203–211.
- Ng, J. W., C. Nielsen, and C. C. St. Clair. 2008. Landscape and traffic factors influencing deer-vehicle collisions in an urban environment. *Human-Wildlife Conflicts* 2:34–47.
- Noro, M. 2010. Analysis of deer ecology and landscape features as factors contributing to deer-vehicle collisions in Hokkaido, Japan. Transportation Research Board, Washington, D.C., USA.
- Osborn, R. G., K. F. Higgins, R. E. Usgard, C. D. Dieter, and R. D. Neiger. 2000. Bird mortality associated with wind turbines at the Buffalo Ridge Wind Resource Area, Minnesota. *The American Midland Naturalist* 143:41–52.

- Pérez-Espona, S., J. M. Pemberton, and R. Putman. 2009. Red and Sika deer in the British Isles, current management issues and management policy. *Mammalian Biology - Zeitschrift für Säugetierkunde* 74:247–262.
- Peterson, C., and T. A. Messmer. 2011. Biological consequences of winter-feeding of mule deer in developed landscapes in northern Utah. *Wildlife Society Bulletin* 35:252–260.
- Pierce, B. M., V. C. Bleich, K. L. Monteith, and R. T. Bowyer. 2012. Top-down versus bottom-up forcing: evidence from mountain lions and mule deer. *Journal of Mammalogy* 93:977–988.
- Pope, C., and A. McEwan. 2012. 2012 UDOT annual statistical summary. Utah Department of Transportation, Salt Lake City, Utah, USA.
- Puglisi, M. J., J. S. Lindzey, and E. D. Bellis. 1974. Factors associated with highway mortality of white-tailed deer. *Journal of Wildlife Management* 38:799–807.
- R Development Core Team. 2012. R: A language and environment for statistical computing, reference index version 2.14.12. R Foundation for Statistical Computing, Vienna, Austria. <<http://www.R-project.org>>. Accessed 15 May 2012.
- Reeve, A. F., and S. H. Anderson. 1993. Ineffectiveness of swareflex reflectors at reducing deer-vehicle collisions. *Wildlife Society Bulletin* 21:127–132.
- Romin, L. A., and J. A. Bissonette. 1996a. Deer-vehicle collisions: status of state monitoring activities and mitigation efforts. *Wildlife Society Bulletin* 24:276–283.
- Romin, L. A., and J. A. Bissonette. 1996b. Temporal and spatial distribution of highway mortality of mule deer on newly constructed roads at Jordanelle Reservoir, Utah. *Western North American Naturalist* 56:1–11.

- Rutberg, A., and R. Naugle. 2008. Deer–vehicle collision trends at a suburban immunocontraception site. *Human–Wildlife Interactions*.
<<http://digitalcommons.unl.edu/hwi/80>>. Accessed 15 May 2013.
- Sawyer, H., C. Lebeau, and T. Hart. 2012. Mitigating roadway impacts to migratory mule deer—A case study with underpasses and continuous fencing. *Wildlife Society Bulletin* 36:492–498.
- Scott, K. M. 1987. Allometry and habitat-related adaptations in the postcranial skeleton of Cervidae. Pages 65–80 *in* C. M. Wemmer, editor. *Biology and management of the cervidae*. Smithsonian Institution Press, Washington, D.C., USA.
- Seiler, A. 2004. Trends and spatial patterns in ungulate-vehicle collisions in Sweden. *Wildlife Biology* 10:301–313.
- Shaw, H. G. 1980. *Ecology of the mountain lion in Arizona*. Arizona Game and Fish, Phoenix, Arizona, USA.
- Sinha, P., and F. Braun. 2010. Regulatory impact analysis (RIA) for existing stationary compression ignition engines NESHAP. United States Environmental Protection Agency, Research Triangle Park, North Carolina, USA.
- Slater, F. M. 2002. An assessment of wildlife road casualties – the potential discrepancy between numbers counted and numbers killed. *Web Ecology* 3:33–42.
- Smallwood, K. S., and C. Thelander. 2008. Bird mortality in the Altamont Pass Wind Resource Area, California. *The Journal of Wildlife Management* 72:215–223.
- Smith, D. R., K. J. Reinecke, M. J. Conroy, M. W. Brown, and J. R. Nassar. 1995. Factors affecting visibility rate of waterfowl surveys in the mississippi alluvial valley. *Journal of Wildlife Management* 59:515–527.

- State Farm. 2012. Deer collisions increase, WV #1 again, Arkansas #9 nationally. State Farm Insurance Company. <http://www.statefarm.com/aboutus/_pressreleases/2012/deer-crash-rankings-ar>. Accessed 29 Apr 2013.
- Sullivan, T. L., and T. A. Messmer. 2003. Perceptions of deer-vehicle collision management by state wildlife agency and department of transportation administrators. *Wildlife Society Bulletin* 31:163–173.
- U. S. Census Bureau. 2010. Resident population data. <<http://www.census.gov/2010census/data/>>. Accessed 25 Apr 2013.
- UDOT. 2010. Vehicle miles of travel. Utah Department of Transportation. <<http://www.udot.utah.gov/>>. Accessed 25 Apr 2013.
- Ward, M. R., D. E. Stallknecht, J. Willis, M. J. Conroy, and W. R. Davidson. 2006. Wild bird mortality and West Nile virus surveillance: biases associated with detection, reporting, and carcass persistence. *Journal of Wildlife Diseases* 42:92–106.
- West, P. W. 2008. UDOT wildlife and domestic animal accident toolkit. Utah Department of Transportation, Salt Lake City, Utah, USA.
- White, G. C., and K. P. Burnham. 1999. Program mark: survival estimation from populations of marked animals. *Bird Study* 46 Supplement 120–138.

Table 2.1. Definitions of parameters in the wildlife fatality estimator that was used to estimate the number of mule deer carcasses from ATV surveys.

Parameter	Definition
\hat{F}	Estimated number of carcasses
c	Number of carcasses observed during surveys
\hat{r}	Carcass persistence
\hat{p}	Search efficiency
\hat{v}	Effective search interval
n	Number of survey transects
s	Number of survey intervals
K	Allows carcass detection to vary by group
π	Probability of a survey transect being included in the sample
i	Individual survey transects
j	Individual survey intervals

Table 2.2. Estimated number of deer-vehicle collisions per season for mule deer on UDOT administered roads in Utah.

DVC Estimate Components	Seasons						Total	95 % CI
	Summer 2010	Fall 2010	Winter 2010	Spring 2011	Summer 2011	Fall 2011		
Automobile Surveys	830	883	1,428	473	674	714	5,002	NA
Carcass Retention for Automobile Surveys	277	294	476	158	225	238	1,667	324-3,914
ATV Survey Estimates	917	691	1,685	643	1,088	503	5,527	2,821-8,936
Coverage	190	176	338	120	187	137	1,148	NA
DVC Estimate	2,214	2,044	3,927	1,394	2,174	1,592	13,344	NA

Table 2.3. AIC table of search efficiency models for deer decoy detection.

Model	Parameters	AICc	ΔAICc	AICc Weight
Null	1	244.51	0.00	0.512
Stage Class	2	246.39	1.88	0.200
Observer	2	246.42	1.91	0.197
Season	3	247.96	3.45	0.091

Table 2.4. AIC table of carcass persistence models.

Model	Parameters	AICc	ΔAICc	AICc Weight
Null	1	53.21	0.00	0.390
Stage Class	2	53.32	0.12	0.368
Distance	2	54.83	1.62	0.173
Season	3	56.72	3.51	0.067

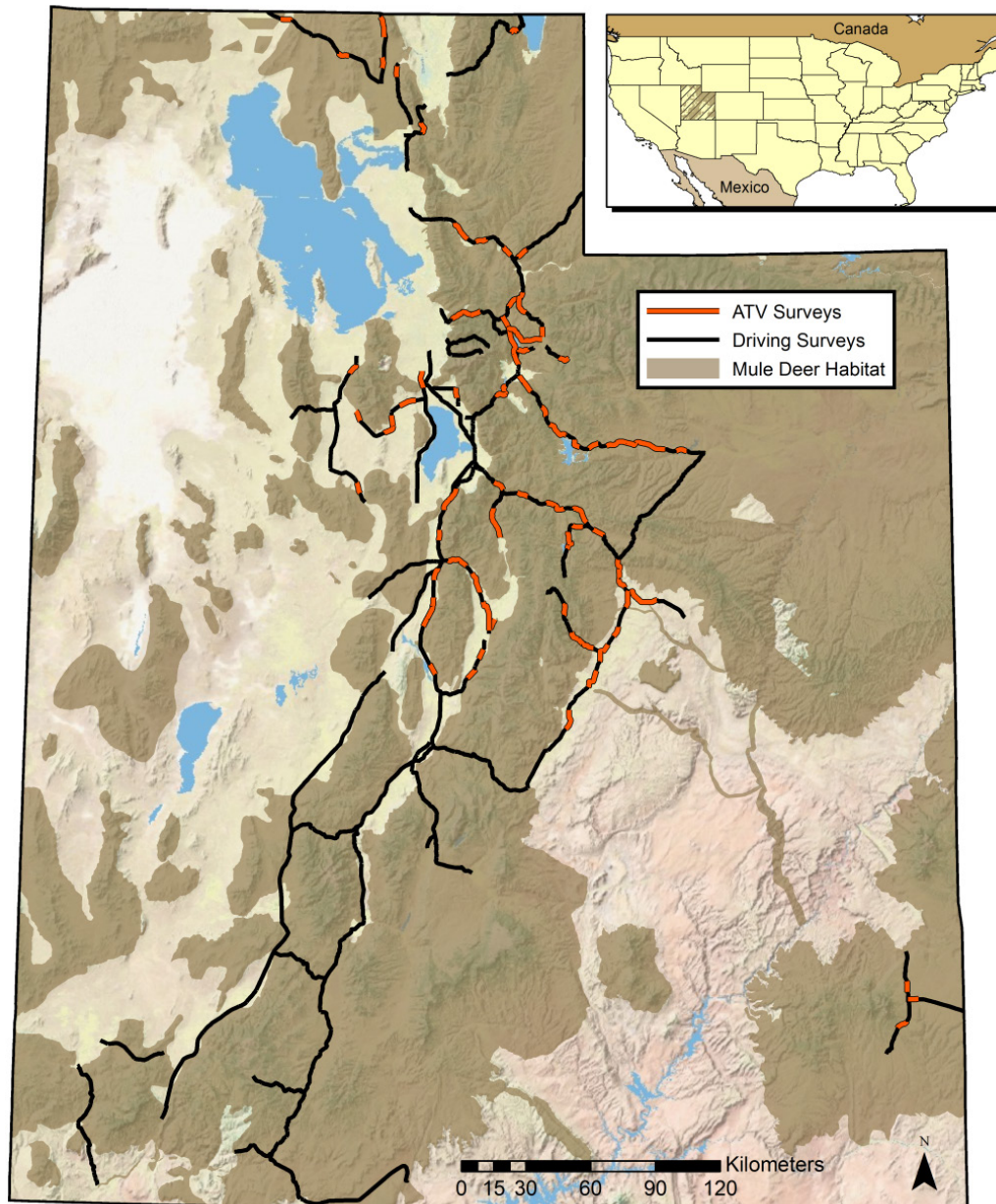


Figure 2.1. Locations of driving surveys and ATV surveys conducted to detect deer carcasses in Utah.



Figure 2.2. Example of an adult deer decoy that was used to estimate carcass detection.

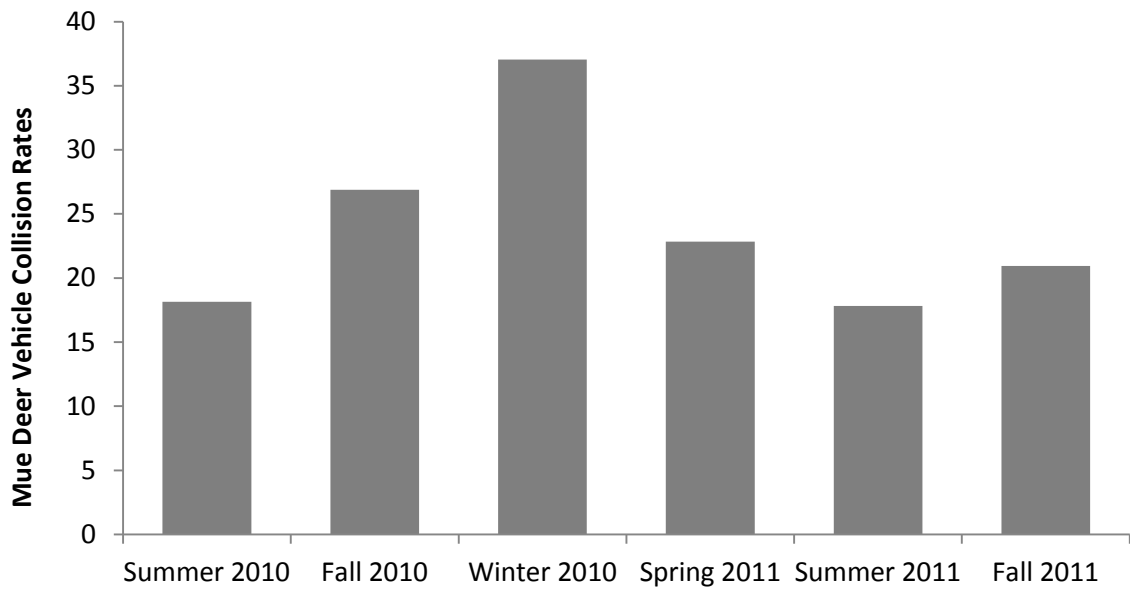


Figure 2.3. Daily vehicle collision rates estimated from carcass surveys for mule deer on UDOT administered routes in Utah.

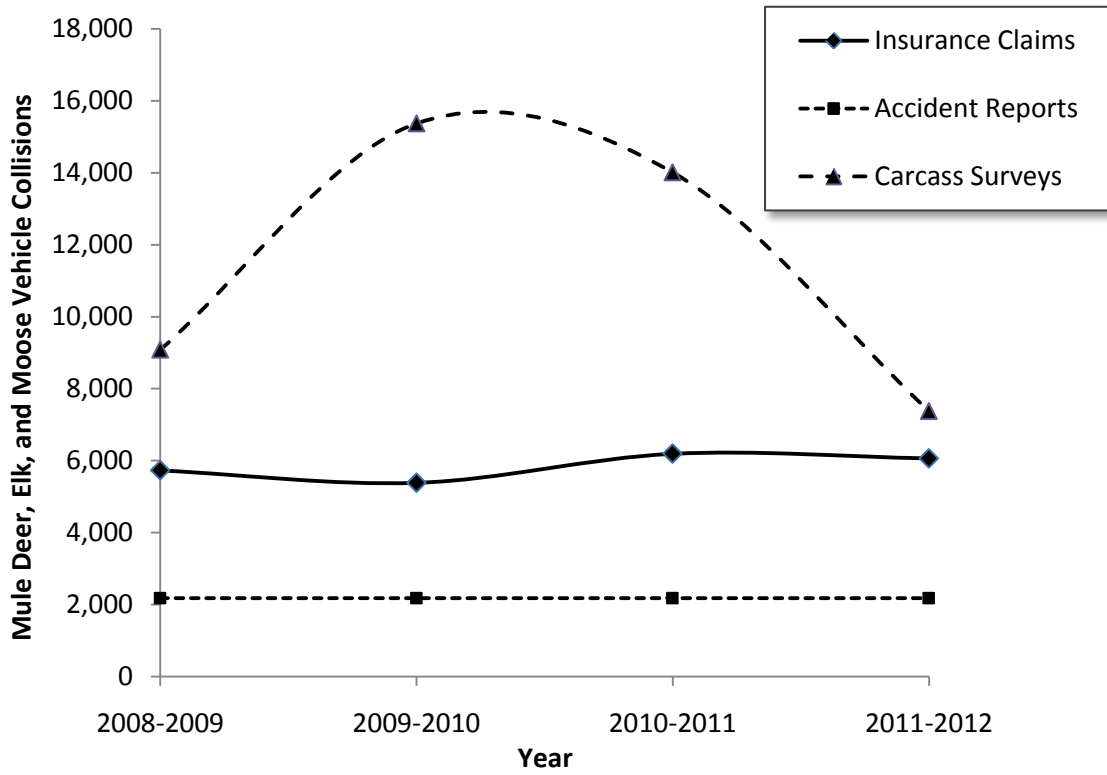


Figure 2.4. Estimates of the number of mule deer, elk, and moose vehicle collisions on UDOT administered routes in Utah (2008-2012) generated from carcass surveys, insurance claims, and accident reports.

CHAPTER 3
WHAT ARE THE DEMOGRAPHIC CONSEQUENCES OF VEHICLE-RELATED
MORTALITY IN MULE DEER?

ABSTRACT

As roads continue to be built and expanded and traffic volumes increase, it is important that managers understand the effects that vehicle-related mortality can have on the population dynamics of deer. Population effects depend not only the number of deer killed but also on the demographic groups involved, because demographic groups have distinct fecundity and survival rates. My objective was to describe the frequency in which mule deer demographic groups were involved in vehicle collisions and to determine if deer were being killed in proportion to their abundance. Additionally, I estimated the age of adult mule deer killed in vehicle collisions to describe the percentage of prime-age individuals. I also compared vehicle collision rates of mule deer, elk, and moose to determine the relative vulnerability of mule deer to vehicle collisions. Finally, I examined trends in mule deer abundance and traffic volumes to determine if roads were affecting abundance. I found that 65 % of mule deer involved in vehicle collisions were female and 40 % were adult females (≥ 2 yrs). Additionally, 98 % of adult females killed in vehicle collisions were prime-aged animals (2-7 yrs old). When we compared the proportion of bucks, does, and fawns killed in vehicle collisions to those in classification surveys of live deer in the fall, we found they differed ($P < 0.01$) with bucks being killed at rate of 2.1-3.0 times their availability. Additionally when we compared vehicle collision rates among deer species for 2010 and 2011, we found that mule deer were 7.4-8.7 times more likely to be involved in vehicle collisions than elk and 1.2-2.0 times more likely than moose. We were unable to detect a negative correlation ($P = 0.55$) between mule deer abundance and increasing traffic volume at the statewide scale extent.

INTRODUCTION

Roads are being built and expanded throughout the developed world to accommodate the increasing human population and demand for transportation of people, goods, and materials (Forman et al. 2003, Larsson et al. 2010, U.S. DOT 2010). As a result, it is becoming increasingly important to understand the effects roads have on wildlife, because the effects of roads appear to be overwhelming negative for most species (Forman and Alexander 1998, Trombulak and Frissell 2000, Roedenbeck et al. 2007, Fahrig and Rytwinski 2009). Species with large movement ranges, low reproductive rates, and naturally low densities are predicted to be affected strongly by roads, because their movement patterns frequently bring them into contact with roads and their populations recover slowly from losses due to vehicle-related mortality (Jaeger et al. 2005, Fahrig and Rytwinski 2009). Compared to small mammals, deer (Cervidae) have lower reproductive rates and population densities, and in temperate climates, deer have seasonal ranges that may be separated up to 160 km (Sawyer et al. 2009). Deer are commonly involved in vehicle collisions in Europe, North America, and Japan (Groot Bruinderink and Hazebroek 1996, Ng et al. 2008, Noro 2010). In the United States alone it has been estimated that there are 1-2 million vehicle collisions with large animals annually, most of which involve deer, that result in > 8 (US \$) billion in damages and ~200 human fatalities (Conover 2001, Langley et al. 2006, Huijser et al. 2008). Additionally, vehicle collisions are nearly always fatal for deer (Allen and McCullough 1976).

Mule deer (*Odocoileus hemionus*), which occur throughout western North America, are regularly involved in vehicle collisions (Reed 1981, Romin and Bissonette 1996, Bissonette and Rosa 2012). The effects that vehicle-related mortality have on population dynamics of mule deer depend not only on the number of individuals killed but also on the demographic groups involved. Deer populations are commonly classified into demographic groups based on sex and life stage characteristics (e.g., fawns, yearlings, and adults) with distinct fecundity and survival

rates (Gaillard et al. 2000). In mule deer populations, adult females are the most important demographic group to population growth (Gaillard et al. 1998), because they have high survival rates and nurse fawns until the termination of parental care (Unsworth et al. 1999, Kie and Czech 2000). Male demographic groups are relatively less important to population growth, because mule deer are polygynous and males do not contribute to the parental care of fawns (Kie and Czech 2000, White et al. 2001). This point has long been recognized and exploited by deer managers when setting harvest quotas. Males are often harvested liberally, while females are harvested conservatively or not at all when population growth is desired (Carpenter 2000, Erickson et al. 2003).

The age of adult deer can also affect their contribution to population dynamics (Robinette et al. 1977), because survival and reproductive rates are highest for prime age individuals (2-7 yrs). As individuals age, survival and reproductive rates may decline (Dixon 1934, Robinette and Gashwiler 1950, Robinette et al. 1977, Gaillard et al. 2007). Factors such as tooth wear can contribute to senescence in deer (Robinette et al. 1957). Overall, mortality factors that remove prime-aged females potentially exert a stronger influence on population dynamics of deer than those that primarily remove senescent females.

Vehicle collision rates may vary between ungulate species due to differences in behavior and habitat use (Ciuti et al. 2012). For instance, several studies have shown that elk (*Cervus elaphus*) avoid roads (Rost and Bailey 1979, Wisdom et al. 2004, Stewart et al. 2010, Montgomery et al. 2013), which may in turn decrease their vulnerability to vehicle collisions. Alternatively a few recent studies have reported that mule deer actually select habitats near roads (Wisdom et al. 2004, Tull and Krausman 2007, Stewart et al. 2010), which could predispose them to vehicle collisions. Vehicle collisions rates of deer species with overlapping distributions have rarely been compared (Groot Bruinderink and Hazebroek 1996), but if differences exist, it would

be beneficial to examine the causes of those differences and tailor mitigation to individual species.

Deer vehicle-collisions (DVCs) have negatively impacted some deer populations. In Florida, 50-74% of mortality for the endangered Key deer (*Odocoileus virginianus clavium*) was due to vehicle collisions (Lopez et al. 2003). Additionally, vehicle collisions were also the leading cause of death (34 % of mortality) for female mule deer in northern Utah, and lower than average survival rates were reported (Peterson and Messmer 2011). However for most deer populations, DVCs appear to play a minor role in population dynamics. For example, white-tailed deer (*Odocoileus virginianus*) are commonly involved in vehicle collisions (Bashore et al. 1985, DeNicola and Williams 2008, McShea et al. 2008), nevertheless the species has continued to increase in abundance and expand its distribution in North America (McCabe and McCabe 1997, McClure et al. 1997)

In Utah, mule deer are frequently killed in vehicle collisions and deer carcasses are regularly observed on roads (West 2008), and as a result there is concern from management agencies, environmental/sportsman organizations, and the public that DVCs may be negatively impacting populations. My objective was to describe the frequency in which mule deer demographic groups were involved in vehicle collisions and determine if deer were being killed in proportion to their abundance. Additionally, I estimated the age of adult mule deer killed in vehicle collisions to describe the percentage of prime-age individuals being removed. I also compared vehicle collision rates of mule deer, elk, and moose (*Alces alces*) in Utah to determine the relative vulnerability of mule deer to vehicle collisions. Finally, I examined trends in mule deer abundance and traffic volumes to determine if roads were affecting abundance at the statewide scale extent.

STUDY AREA

The study was conducted in the state of Utah (219,807 km²), which is located in the southwestern United States on the western edge of the Rocky Mountains (Fig. 3.1). Much of the state is semi-arid (127-381 mm precipitation) (Gillies and Ramsey 2009). Utah is the second driest state in the United States (Fisher 2013). Topography, however, is highly variable (663-4,413 m) and precipitation increases with elevation (Leydsman McGinty and McGinty 2009); as a result some high elevation areas may receive in excess of >1,473 mm of precipitation (Gillies and Ramsey 2009). The majority of Utah is comprised of three ecoregions: the Colorado Plateau, the Wasatch and Uinta Mountains, and the Central Basin and Range (Griffith and Omernik 2009). The landscape is ecologically diverse with vegetation cover types that vary from salt desert shrub to alpine tundra (Welsh et al. 1993). Utah is inhabited by a suite of ungulates that include mule deer, elk, moose, and white-tailed deer (McClure et al. 1997). Of those species, mule deer were the most abundant (~300,000 individuals) and widely distributed (Bernales et al. 2011), and their range coincided with or was adjacent to nearly all mountainous areas and major human population centers in the state. Elk were less abundant (~75,000 individuals) than mule deer, but elk abundance has consistently grown over the past decade (Bernales et al. 2011). The distribution of elk closely resembled that of mule deer but was more restricted in some locations. Moose were far less abundant (~2,700 individuals) than both mule deer and elk, and their range was generally limited to the central and northern portions of the state (Bernales et al. 2011) but the distribution of moose generally overlapped mule deer and elk distributions. White-tailed deer existed in very limited numbers in the extreme northern portion of Utah (McClure et al. 1997), and no estimates of abundance are available because populations were not monitored by the Utah Division of Wildlife Resources (UDWR). All deer species are harvested in Utah, with harvest being strongly biased towards males (Bernales et al. 2011).

In Utah, 75% of the land area is federally or state owned, and as a result much of the state is rural (Leydsman McGinty 2009a). Utah, however, is the 3rd fastest growing state in the United States and is rapidly becoming urbanized (Leydsman McGinty 2009b, U.S. Census Bureau 2010). The growing human population has increased demand for transportation, and traffic volumes have doubled in the past 30 years (UDOT 2010). In 2010, 42.8 billion km were driven on 73,413 km of roads (UDOT 2010, Pope and McEwan 2012). Deer-vehicle collisions in Utah are a considerable public safety concern in Utah that has resulted in >7 (US \$) million in damages each year (Bissonette et al. 2008). In the past, most reported DVCs in Utah have involved mule deer (West 2008).

METHODS

Demographics

To quantify the demographics of mule deer that were killed in vehicle collisions, I conducted carcass surveys throughout northern, central, and southeastern Utah. Carcass survey transects (4.8 km) were selected using a proportional sampling design (Thompson 1992). Transects were surveyed every 14 days by trained technicians employed by Utah State University using All-Terrain Vehicles (ATVs). During a carcass survey the technician functioned as both driver and observer. ATVs were driven at 8- 16 kmph on the shoulder and the median of roads within transects. Technicians recorded carcass locations using a Garmin GPS unit (Model eTrex Legend H, Garmin International, Inc., Olathe, Kansas, USA). They also documented the sex and stage class of carcasses (juvenile, yearling, and adult) observed. All carcasses detected during surveys were marked with an orange, serial numbered tag that was placed around the hind leg to insure that carcasses were not double counted during future surveys. Technicians also examined and marked all deer carcasses that were opportunistically observed while driving to and from

survey transects. Carcasses for which the stage class and sex could not be determined were excluded from the analysis. I tested for differences in the proportion of deer that were in each demographic using Chi square tests. All statistical analyses for this study were performed in R (R Development Core Team 2012).

To determine if mule deer were being killed in vehicle collisions in proportion to their availability, I compared carcass survey data to classification surveys of live deer. Classification surveys were conducted by Utah Division of Wildlife Resources (UDWR) biologists during early winter (November-December) when deer were congregated on winter ranges. Deer were classified as bucks (males ≥ 1.5 yrs old), does (females ≥ 1.5 yrs old), and fawns (males and females ≤ 0.5 yrs old). To make carcass survey data comparable to UDWR classification surveys, I combined adult and yearling groups for both males and females into buck and doe groups. Additionally, I counted male and female fawn groups as one group. Classification data used for comparison was obtained from deer management units that coincided with carcass survey locations. I tested for differences between carcass survey data and live classifications using Chi square tests.

To estimate the age of adult deer, I extracted lower incisors from carcasses and sent them to Dr. R. Larsen's lab at Brigham Young University (Provo, Utah, USA) for cementum annuli analysis. Teeth were cross sectioned, stained, and age estimates were generated using standard techniques (Erickson and Seliger 1969). The accuracy of age estimates using this method is typically $>90\%$ for mule deer (Hamlin et al. 2000). Age estimates were reported as the base year, and June 15th was used as transition date from one year to the next because that was the peak fawning date in Utah (Robinette and Gashwiler 1950). Because age distributions were skewed for both males and females, I reported medians instead of means, and I tested for differences using a nonparametric Wilcoxon rank-sum test.

Vehicle Collision Rates

To quantify vehicle collision rates for mule deer, elk, and moose, I used carcass survey data collected by Utah Department of Transportation (UDOT) contractors using automobiles. Automobile surveys have been conducted in Utah since at least 1998 (Bissonette and Rosa 2012). UDOT contractors drove ~1,750 km of roads 2 times per week throughout the year. Surveys were generally performed by a single person, who acted as driver and observer. Survey vehicles were driven at the posted speed limit. If the road had multiple traffic lanes, the survey automobile was driven in the slow lane, nearest to the shoulder of the road. Undivided roads were surveyed in only one direction, while divided roads with a median were surveyed in both directions. During surveys, UDOT contractors removed all carcasses that were detected on the road surface, the median, and on the road shoulder out to the reflective highway markers. They kept detailed records of the species removed and their locations. Driving surveys were minimum estimates of vehicle collision rates, because they do not account carcass detection probabilities (Olson, Bissonette, and Coster, Utah State University, unpublished data).

I also quantified the overlap of mule deer, elk, and moose habitat using ArcGIS 10.1 and distribution layers that were generated by the UDWR for each species (Utah AGRC 2012).

Mule Deer Abundance and Traffic Volumes

Mule deer abundance was estimated annually by the UDWR using a combination of ground and aerial counts for deer management units throughout the state; however, no measures of uncertainty were reported for abundance estimates (Bernales et al. 2011). Traffic volume data were obtained from the Utah Department of Transportation for the study area (UDOT 2012). Traffic volumes were reported by UDOT as average annual daily traffic (AADT) during each calendar year. Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

RESULTS

Demographics

From July 2010 to December 2011, I examined 1,257 mule deer carcasses. Female deer represented 65 % of all deer carcasses. When I compared the proportion of deer in each of the 6 demographic groups, I found that they differed ($\chi^2 [2, n = 1,257] = 41.9, P < 0.01$). Adult females were the largest group at 40 %, and all other demographic groups had similar and ranged between 10 % and 14 % (Fig. 3.2). This indicated that adult females were reported in carcass surveys at rate that was 2.8-3.9 times more than any other demographic group.

I obtained age estimates for 524 adult mule deer that were killed in vehicle collisions. Ages of female and male deer differed ($W = 29118, P < 0.01$), and the median age for females was 4 yrs and for males it was 3 yrs (Fig. 3.3). Nearly all adult females (98 %) and males (98 %) were 2-7 yrs old and would be considered prime-age individuals. The oldest observed female was 13 yrs old and the oldest male was 9 yrs old.

When I compared the proportion of bucks, does, and fawns in carcass surveys to those in classification surveys of live deer, I found they differed for both fall 2010 ($X^2 [2, n = 18,221] = 40.9, P < 0.01$) and fall 2011 ($\chi^2 [2, n = 16,426] = 38.4, P = < 0.01$). During both years, there were fewer fawns and does in carcass surveys than in live surveys, but 95 % confidence intervals for those groups overlapped indicating the results were not statistically significant (Fig. 3.4). The proportion of bucks did differ significantly and was 205-296 % higher in carcass surveys than live surveys.

Vehicle Collision Rates

The distribution of mule deer, elk, and moose in Utah was highly congruent, with 96 % of elk habitat and 99 % of moose habitat corresponding with the distribution of mule deer (Fig.

3.1). However, vehicle collisions rates varied widely among species (Fig. 3.5). Mule deer experienced the highest vehicle collision rates during both 2009-2010 (18.3 per 1,000 deer) and 2010-2011 (18.3 per 1,000 deer), which were 739-869 % higher than those experience by elk (2.1-2.5 per 1,000 elk) and 119-197 % than those experienced by moose (9.3-15.3 per 1,000 moose).

Mule deer Abundance and Traffic Volumes

From 1992 to 2011, mean mule deer abundance in Utah was 291,044 individuals ($n = 20$, $SD = 26,359$) (Bernales et al. 2011). Abundance peaked in 1992, but declined to its lowest point in 1993 due to severe winter weather (Fig. 3.6). Although mule deer abundance was highly variable over the 20 year period, there was no linear trend in abundance ($F_{1,18} = 0.28$, $P = 0.60$, $R^2 = 0.02$). During the same time period, mean traffic volume for the state was 37.3 billion km/year ($n = 20$, $SD = 4.0$). The lowest traffic volumes occurred in 1992 and the highest in 2007 (Fig. 3.6). There was a positive linear trend in traffic volume ($F_{1,18} = 178.8$, $P = < 0.01$, $R^2 = 0.91$), and traffic volumes increased 2 % annually over the 20 year period. There was no evidence that mule deer abundance and traffic volumes were correlated at the statewide scale extent ($F_{1,18} = 0.38$, $P = 0.55$, $R^2 = 0.02$).

DISCUSSION

Deer demographic groups vary in their contribution to population growth (Gaillard et al. 1998). As a result the effect that DVCs have on population growth is determined not only by the number of deer that are killed but also the demographic groups that are differentially impacted. In polygynous species, individual females are more vital to population growth than males. In deer, adult female deer are generally considered the most important demographic group (Gaillard et al. 1998). In Utah, I found that nearly two-thirds of mule deer killed in vehicle collisions were

female and 40 % were adult females. My data suggest that vehicle collisions could have a strong negative influence on deer abundance, because a high percentage of females and adult females were being removed.

It appears common that most vehicle collisions involve female deer. Romin and Bissonette (1996) reported almost identical findings to ours for a mule deer population in central Utah, with 68 % of vehicle collisions involving females. Additionally, they found that 52 % were does. The doe designation represented a combination of the yearling female and adult female demographic groups. When I combined my estimates for yearling females and adult females, I found that 50 % of deer involved in vehicle collisions belonged to these groups. For white-tailed (WT) deer in Michigan, Allen and McCullough also observed that two-thirds of deer killed in vehicle collisions were female (Allen and McCullough 1976). Bellis and Graves (1971) observed a similar but slightly lower percentage of female (WT) deer (58 %) in Pennsylvania.

Does are more frequently involved in vehicle collisions because most hunted deer populations are strongly skewed towards females (Kie and Czech 2000). If I assumed a fawn sex ratio of 1:1 (Robinette and Gashwiler 1950), then classification surveys of live deer indicate 71-73 % of the population consisted of females, which was only slightly higher than what I observed in carcass surveys (66 %). The female biased population structure in Utah is largely the result of the male biased harvest strategy. During my study, 7.6-11.6 times more males were harvested than females, while males represented only 27-29 % of the population (2011). In central Utah, Lehnert et al. (1998) observed that does were killed in proportion to their availability. In Wyoming, Goodwin and Ward (1976) reported the demographic composition DVCs for mule deer was similar to herd composition. Additionally, DeNicola and Williams (2008) showed experimentally that reducing white-tailed deer populations resulted in a proportional decrease in DVCs, indicating that DVCs are a reflection of the deer population in general.

While the composition of DVCs generally resembles population structure, there may be times when certain demographic groups are more vulnerable. For example in Wisconsin, Jahn (1959) reported that the number of DVCs involving male (WT) deer increased sharply during fall (October-November), presumably in response to bucks increasing their movement rates to search for females during the breeding season. My data also support this pattern. During fall, the proportion of mule deer bucks killed in vehicle collisions was 2-3 times their proportional availability in the fall population. Lehnert et al. (1998) also reported that mule deer bucks were killed at a rate that was 2 times their availability not only in the fall but throughout the year. Because male mule deer are already heavily harvested, managers may wish to consider vehicle collision losses when setting harvest quotas. Additionally, mitigation could potentially increase the number of male deer available for harvest, which would result in more opportunity for sportsmen.

In addition to high percentage of adult females killed by vehicle collisions in my study area, nearly all (98 %) adults were prime-aged individuals. This result was consistent with the limited research that exists; Romin and Bissonette (1996) reported that all adult deer involved in vehicle collisions in their study in central Utah were prime-aged individuals. The implications are subtle but important, because prime-aged females typically have the highest survival and reproductive rates. For example in Utah, Robinette et al. (1977) reported 18 % higher pregnancy rates and 30 % higher fecundity rates for prime-aged female mule deer. Additionally, data from southeast Idaho indicate that survival rates decrease ~4 % annually for senescing female mule deer (Hurley and Zager 2007). The effect that vehicle collisions have on population abundance is likely strengthened because most adult females killed were prime-aged.

Mule deer also appeared to be more vulnerable to vehicle collisions than other ungulate species. In my study area the distribution of elk and moose largely coincided with that of mule

deer, but vehicle collision rates for mule deer were 7.4-8.7 times higher than elk and 1.2-2.0 higher than moose. Additionally, the vehicle collisions rates that I reported were not corrected for carcass detection. If these estimates would have been corrected for detection bias, the disparity in vehicle collision rates would have likely increased, because mule deer (~45-113 kg) are smaller than elk (~265-320 kg) and moose (up to 771 kg) (Wisdom and Cook 2000, Bowyer et al. 2003, UDWR 2011). As a result, mule deer likely have the lowest detection rate of three deer species, and vehicle collisions rates were potentially underestimated the greatest for them. However, I did not measure detection rates and was unable to document whether this actually occurred.

I know of no other peer reviewed studies that have compared vehicle collision rates for mule deer, elk, and moose with overlapping distributions. The only comparable study that I am aware of was conducted by Groot Bruinderink and Hazebroek (Groot Bruinderink and Hazebroek 1996) in Norway, where they reported that vehicle collision rates for roe deer (*Capreolus capreolus*) were 3.2 times higher than those for red deer (*Cervus elaphus*) and 1.5 times higher than those for moose, suggesting a pattern similar to what I observed in Utah. Roe deer are smaller than mule deer, but fill a comparable ecological niche in Europe (Danilkin 1995).

It is unclear why mule deer would be so much more vulnerable to vehicle collisions than elk, given that the two species have similar distributions and seasonal movement patterns. Some of the dissimilarity no doubt is related to differing behavioral response to roads. For example, Fahrig and Rytwinski (Fahrig and Rytwinski 2009) predicted that species that show no avoidance of roads will be impacted more than those that avoid roads. Available reports indicate that elk generally avoid roads (Rost and Bailey 1979, Wisdom and Cook 2000, Rowland et al. 2005). Early evidence for mule deer indicated similar road avoidance (Rost and Bailey 1979). However, several studies using modern techniques have indicated that mule deer actually select areas near roads (Wisdom et al. 2004, Tull and Krausman 2007, Stewart et al. 2010). This could explain a

great deal of the difference in vehicle collision rates between the species. The reasons why mule deer are selecting habitat near roads are uncertain. Stewart et al (Stewart et al. 2010) and Wisdom et al. (Wisdom et al. 2004) both suggested that elk, which are socially dominate and increasing in abundance, may be displacing deer from habitats that are farther from roads. However, this hypothesis still needs to be tested experimentally. Additionally there is evidence that during winter, snow accumulation may force mule deer into habitats that are near roads with high traffic volumes, thus increasing vehicle collision rates (Olson and Bissonette, Utah State University, unpublished data).

Although it is uncommon for vehicle collisions to cause deer abundance to decline, some populations have been significantly affected by vehicle-related mortality (Lehnert et al. 1998, Lopez et al. 2003, Peterson and Messmer 2011). In my study area, I was able to establish that vehicle collisions removed a high percentage of adult females and that mule deer were more vulnerable to vehicle collisions than other deer species, but I was unable to demonstrate that vehicle collisions were causing a decrease in mule deer abundance. Over the past 20 years in Utah, traffic volumes have increased 42 % but the long-term trend for mule deer abundance has remained stable. Given that deer populations can sustain significant annual mortality (McCullough 1999), it is probable that vehicle-related mortality levels for mule deer are not yet high enough across the state to cause population declines, even though I estimated that 2-5 % of the population was killed in vehicle collisions each year (Olson, Bissonette, and Coster, Utah State University, unpublished data). Additionally, mitigation measures such as wildlife crossings and exclusionary fencing have been used in Utah since the 1970's to improve motorist safety and reduce deer mortality (Cramer and Bissonette 2006, West 2008, Cramer 2012). It is likely that mitigation has partially offset some of the effects of increasing traffic volumes and vehicle-related mortality on mule deer. As the road network is expanded and traffic volumes continue to

increase, mitigation will likely become more crucial in reducing the negative effects of roads on deer.

LITERATURE CITED

- Allen, R. E., and D. R. McCullough. 1976. Deer-car accidents in southern Michigan. *Journal of Wildlife Management* 40:317–325.
- Bashore, T. L., W. M. Tzilkowski, and E. D. Bellis. 1985. Analysis of deer-vehicle collision sites in Pennsylvania. *Journal of Wildlife Management* 49:769–774.
- Bellis, E. D., and H. B. Graves. 1971. Deer mortality on a Pennsylvania interstate highway. *Journal of Wildlife Management* 35:232–237.
- Bernales, H. H., K. R. Hersey, and A. Aoude. 2011. Utah big game annual report 2011. Utah Division of Wildlife Resources, Salt Lake City, Utah, USA.
- Bissonette, J. A., C. A. Kassar, and J. C. Cook. 2008. Assessment of costs associated with deer-vehicle collisions: human death and injury, vehicle damage, and deer loss. *Human Wildlife Conflicts* 2:17–27.
- Bissonette, J. A., and S. Rosa. 2012. An evaluation of a mitigation strategy for deer-vehicle collisions. *Wildlife Biology* 18:414–423.
- Bowyer, R., V. Van Ballenberghe, and J. Kie. 2003. Moose: *Alces alces*. Pages 931–964 in G. Feldhamer, B. Thompson, and J. Chapman, editors. *Wild mammals of North America: biology, management and conservation*. Johns Hopkins University Press, Baltimore, Maryland, USA.
- Carpenter, L. H. 2000. Harvest management goals. Pages 192–213 in S. Demarais and P. R. Krausman, editors. *Ecology and management of large mammals in North America*. Prentice Hall, Upper Saddle River, New Jersey, USA.

- Ciuti, S., J. M. Northrup, T. B. Muhly, S. Simi, M. Musiani, J. A. Pitt, and M. S. Boyce. 2012. Effects of humans on behaviour of wildlife exceed those of natural predators in a landscape of fear. *PLoS ONE* 7:e50611.
- Conover, M. R. 2001. Resolving human-wildlife conflicts: the science of wildlife damage management. CRC Press, Boca Raton, Florida, USA.
- Cramer, P., and J. Bissonette. 2006. Wildlife crossings in North America. Transportation Research Board. <http://digitalcommons.usu.edu/wild_facpub/1206>. Accessed 15 Apr 2013.
- Cramer, P. 2012. Determining wildlife use of wildlife crossing structures under different scenarios. Utah State University. Report UT-12 .07, Logan, Utah, USA. <<http://trid.trb.org/view.aspx?id=1147953>>. Accessed 8 Jul 2013.
- Danilkin, A. 1995. Behavioural ecology of Siberian and European roe deer. Chapman and Hall Wildlife Ecology and Behaviour Series, Springer, New York, New York, USA.
- DeNicola, A. J., and S. C. Williams. 2008. Sharpshooting suburban white-tailed deer reduces deer-vehicle collisions. *Human-Wildlife Interactions* 2:28–33.
- Dixon, J. S. 1934. A study of life history and food habits of mule deer in California. *California Fish and Game* 20:1–146.
- Erickson, G. L., J. R. Heffelfinger, and J. H. Ellenberger. 2003. Potential effects of hunting and hunt structure on mule deer abundance and demographics. Pages 119–138 in J. C. deVos, M. R. Conover, and N. E. Headrick, editors. *Mule deer conservation: issues and management*. Jack H. Berryman Institute Press, Logan, Utah, USA.
- Erickson, J. A., and W. G. Seliger. 1969. Efficient sectioning of incisors for estimating ages of mule deer. *Journal of Wildlife Management* 33:384–388.

- Fahrig, L., and T. Rytwinski. 2009. Effects of roads on animal abundance: an empirical review and synthesis. *Ecology and Society* 14:21.
- Fisher, A. L. 2013. Physical geography of Utah. Utah.gov.
<http://historytogo.utah.gov/utah_chapters/the_land/physicalgeographyofutah.html>.
Accessed 27 Jul 2013.
- Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics* 29:207–231.
- Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. *Road ecology: science and solutions*. Island Press, Washington, D.C., USA.
- Gaillard, J.-M., M. Festa-Bianchet, and N. G. Yoccoz. 1998. Population dynamics of large herbivores: variable recruitment with constant adult survival. *Trends in Ecology & Evolution* 13:58–63.
- Gaillard, J.-M., M. Festa-Bianchet, N. G. Yoccoz, A. Loison, and C. Toigo. 2000. Temporal variation in fitness components and population dynamics of large herbivores. *Annual Review of Ecology and Systematics* 31:367–393.
- Gaillard, J.-M., A. Viallefont, A. Loison, and M. Festa-Bianchet. 2007. Assessing senescence patterns in populations of large mammals. *Animal Biodiversity and Conservation* 27:47–58.
- Gillies, R. R., and R. D. Ramsey. 2009. Climate of Utah. Pages 39–45 *in* R. E. Banner, B. D. Baldwin, and E. I. Leydsman McGinty, editors. *Rangelands resources of Utah*. Utah State University Cooperative Extension Service, Logan, Utah, USA.

- Goodwin, G. A., and A. L. Ward. 1976. Mule deer mortality on interstate 80 in Wyoming: causes, patterns, and recommendations. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, USA.
- Griffith, G. E., and J. M. Omernik. 2009. Ecoregions of Utah (EPA). C. J. Cleveland, editor. Encyclopedia of Earth. Environmental Information Coalition, Washington, D.C., USA. <[http://www.eoearth.org/article/Ecoregions_of_Utah_\(EPA\)](http://www.eoearth.org/article/Ecoregions_of_Utah_(EPA))>. Accessed 11 May 2013.
- Groot Bruinderink, G. W. T. A., and E. Hazebroek. 1996. Ungulate traffic collisions in Europe. *Conservation Biology* 10:1059–1067.
- Hamlin, K. L., D. F. Pac, C. A. Sime, R. M. DeSimone, and G. L. Dusek. 2000. Evaluating the accuracy of ages obtained by two methods for Montana ungulates. *Journal of Wildlife Management* 64:441–449.
- Huijser, M. P., P. T. McGowen, J. Fuller, A. Hardy, and A. Kociolek. 2008. Wildlife-vehicle collision reduction study: report to Congress. Western Transportation Institute, Bozeman, Montana, USA.
- Hurley, M., and P. Zager. 2007. Southeast mule deer ecology. Idaho Fish and Game, Boise, Idaho, USA.
- Jaeger, J. A. G., J. Bowman, J. Brennan, L. Fahrig, D. Bert, J. Bouchard, N. Charbonneau, K. Frank, B. Gruber, and K. T. von Toschanowitz. 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. *Ecological Modelling* 185:329–348.
- Jahn, L. R. 1959. Highway mortality as an index of deer-population change. *Journal of Wildlife Management* 23:187–197.

- Kie, J. G., and B. Czech. 2000. Mule and black-tailed deer. Pages 629–657 *in* S. Demarais and P. R. Krausman, editors. Ecology and management of large mammals in North America. Prentice Hall, Upper Saddle River, New Jersey, USA.
- Langley, R. L., S. A. Higgins, and K. B. Herrin. 2006. Risk factors associated with fatal animal-vehicle collisions in the United States, 1995–2004. *Wilderness & Environmental Medicine* 17:229–239.
- Larsson, P., S. W. A. Dekker, and C. Tingvall. 2010. The need for a systems theory approach to road safety. *Safety Science* 48:1167–1174.
- Lehnert, M. E., J. A. Bissonette, and J. W. Haefner. 1998. Deer (Cervidae) highway mortality: using models to tailor mitigative efforts. *Gibier Faune Sauvage, Game Wildlife*. 15:835–841.
- Leydsman McGinty, E. I. 2009a. Land ownership in Utah. Pages 9–23 *in* R. E. Banner, B. D. Baldwin, and E. I. Leydsman McGinty, editors. Rangelands resources of Utah. Utah State University Cooperative Extension Service, Logan, Utah, USA.
- Leydsman McGinty, E. I. 2009b. Urbanization in Utah. Pages 153–156 *in* R. E. Banner, B. D. Baldwin, and E. I. Leydsman McGinty, editors. Rangelands resources of Utah. Utah State University Cooperative Extension Service, Logan, Utah, USA.
- Leydsman McGinty, E. I., and C. M. McGinty. 2009. Physiography of Utah. Pages 24–28 *in* R. E. Banner, B. D. Baldwin, and E. I. Leydsman McGinty, editors. Rangelands resources of Utah. Utah State University Cooperative Extension Service, Logan, Utah, USA.
- Lopez, R. R., M. E. P. Vieira, N. J. Silvy, P. A. Frank, S. W. Whisenant, and D. A. Jones. 2003. Survival, mortality, and life expectancy of Florida key deer. *Journal of Wildlife Management* 67:34–45.

- McCabe, T. R., and R. E. McCabe. 1997. Recounting whitetails past. Pages 11–26 in W. J. McShea, H. B. Underwood, and J. H. Rappole, editors. *The science of overabundance: deer ecology and population management*. Smithsonian Institution Press, Washington, D.C., USA.
- McClure, M. F., J. A. Bissonette, M. R. Conover, and D. D. Austin. 1997. Range expansion of white-tailed deer (*Odocoileus virginianus*) into urban and agricultural areas of Utah. *Western North American Naturalist* 57:278–280.
- McCullough, D. R. 1999. Density dependence and life-history strategies of ungulates. *Journal of Mammalogy* 80:1130–1146.
- McShea, W. J., C. M. Stewart, L. J. Kearns, S. Liccioli, and D. Kocka. 2008. Factors affecting autumn deer–vehicle collisions in a rural Virginia County. *Human-Wildlife Conflicts* 2:110–121.
- Montgomery, R. A., G. J. Roloff, and J. J. Millspaugh. 2013. Variation in elk response to roads by season, sex, and road type. *Journal of Wildlife Management* 77:313–325.
- Ng, J. W., C. Nielsen, and C. C. St. Clair. 2008. Landscape and traffic factors influencing deer-vehicle collisions in an urban environment. *Human-Wildlife Conflicts* 2:34–47.
- Noro, M. 2010. Analysis of deer ecology and landscape features as factors contributing to deer-vehicle collisions in Hokkaido, Japan. Transportation Research Board, Washington, D.C., USA.
- Peterson, C., and T. A. Messmer. 2011. Biological consequences of winter-feeding of mule deer in developed landscapes in northern Utah. *Wildlife Society Bulletin* 35:252–260.
- Pope, C., and A. McEwan. 2012. 2012 UDOT annual statistical summary. Utah Department of Transportation, Salt Lake City, Utah, USA.

- R Development Core Team. 2012. R: A language and environment for statistical computing, reference index version 2.14.12. R Foundation for Statistical Computing, Vienna, Austria. <<http://www.R-project.org>>. Accessed 15 May 2012.
- Reed, D. F. 1981. Conflicts with civilization. Pages 509–545 *in* O. C. Walmo, editor. Mule and black-tailed deer of North America. University of Nebraska Press, Lincoln, Nebraska, USA.
- Robinette, W. L., and J. S. Gashwiler. 1950. Breeding season, productivity, and fawning period of the mule deer in Utah. *Journal of Wildlife Management* 14:457–469.
- Robinette, W. L., D. A. Jones, G. Rogers, and J. S. Gashwiler. 1957. Notes on tooth development and wear for Rocky Mountain mule deer. *Journal of Wildlife Management* 21:134–153.
- Robinette, W. L., N. V. Hancock, and D. A. Jones. 1977. The Oak Creek mule deer herd in Utah. Utah Division of Wildlife Resources, Salt Lake City, Utah, USA.
- Roedenbeck, I. A., L. Fahrig, C. S. Findlay, J. E. Houlahan, J. A. G. Jaeger, N. Klar, S. Kramer-Schadt, and E. A. van der Grift. 2007. The Rauschholzhausen agenda for road ecology. *Ecology and Society* 12:11.
- Romin, L. A., and J. A. Bissonette. 1996. Temporal and spatial distribution of highway mortality of mule deer on newly constructed roads at Jordanelle Reservoir, Utah. *Western North American Naturalist* 56:1–11.
- Rost, G. R., and J. A. Bailey. 1979. Distribution of mule deer and elk in relation to roads. *Journal of Wildlife Management* 43:634–641.
- Rowland, M. M., M. J. Wisdom, B. K. Johnson, and M. A. Penninger. 2005. Effects of roads on elk: implications for management in forested ecosystems. Pages 42–52 *in* M. J. Wisdom, editor. *The Starkey Project: a synthesis of long-term studies of elk and mule deer*. Alliance Communications Group, Lawrence, Kansas, USA.

- Sawyer, H., M. J. Kauffman, R. M. Nielson, and J. S. Horne. 2009. Identifying and prioritizing ungulate migration routes for landscape-level conservation. *Ecological Applications* 19:2016–2025.
- Stewart, K. M., R. T. Bowyer, J. G. Kie, and M. A. Hurley. 2010. Spatial distributions of mule deer and North American elk: resource partitioning in a sage-steppe environment. *The American Midland Naturalist* 163:400–412.
- Thompson, S. E. 1992. *Sampling*. John Wiley & Sons, Inc., New York, New York, USA.
- Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14:18–30.
- Tull, J. C., and P. R. Krausman. 2007. Habitat use of a fragmented landscape by females in a small population of desert mule deer. *The Southwestern Naturalist* 52:104–109.
- U.S. Census Bureau. 2010. Resident population data. <<http://www.census.gov/2010census/data/>>. Accessed 25 Apr 2013.
- U.S. DOT. 2010. 2010 status of the Nation's highways, bridges, and transit: conditions and performance. United Department of Transportation, Washington, D.C., USA.
- UDOT. 2012. Traffic on Utah's highways. Utah Department of Transportation. <<http://www.udot.utah.gov/>>. Accessed 1 Jul 2013.
- UDWR. 2011. Mule deer (*Odocoileus hemionus*). Wildlife Notebook Series, Wildlife Notebook Series 13, Utah Division of Wildlife Resources, Salt Lake City, Utah, USA.
- Unsworth, J. W., D. F. Pac, G. C. White, and R. M. Bartmann. 1999. Mule deer survival in Colorado, Idaho, and Montana. *Journal of Wildlife Management* 63:315–326.
- Utah AGRC. 2012. Roads and highway system. Automate Geographic Reference Center. <<http://gis.utah.gov/>>. Accessed 8 Sept 2012.

- Welsh, S. L., A. N. Atwood, and L. C. Higgins, editors. 1993. A Utah flora. Brigham Young University, Provo, Utah, USA.
- West, P. W. 2008. UDOT wildlife and domestic animal accident toolkit. Utah Department of Transportation, Salt Lake City, Utah, USA.
- White, G. C., D. J. Freddy, R. B. Gill, and J. H. Ellenberger. 2001. Effect of adult sex ratio on mule deer and elk productivity in Colorado. *Journal of Wildlife Management* 65:543–551.
- Wisdom, M. J., and J. G. Cook. 2000. North American elk. Pages 694–735 in S. Demarais and P. R. Krausman, editors. *Ecology and management of large mammals in North America*. Prentice Hall, Upper Saddle River, New Jersey, USA.
- Wisdom, M. J., N. J. Cimon, B. K. Johnson, E. O. Garton, and J. W. Thomas. 2004. Spatial partitioning by mule deer and elk in relation to traffic. Pages 509–530 *in*. *Transactions of the 69th North American Wildlife and Natural Resources Conference*. Wildlife Management Institute, Spokane, Washington, USA.

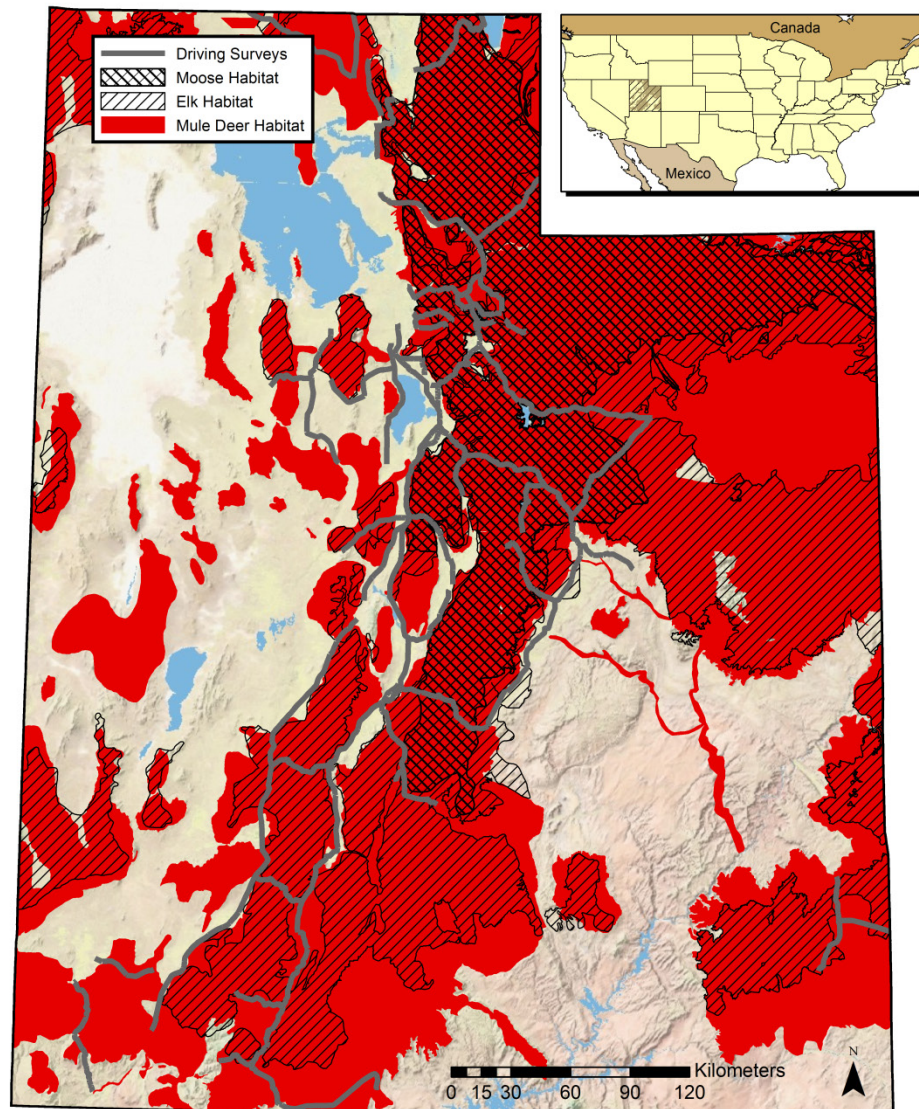


Figure 3.1. Mule deer, elk, and moose habitat in Utah, as well as the roads that were surveyed for carcasses of those species.

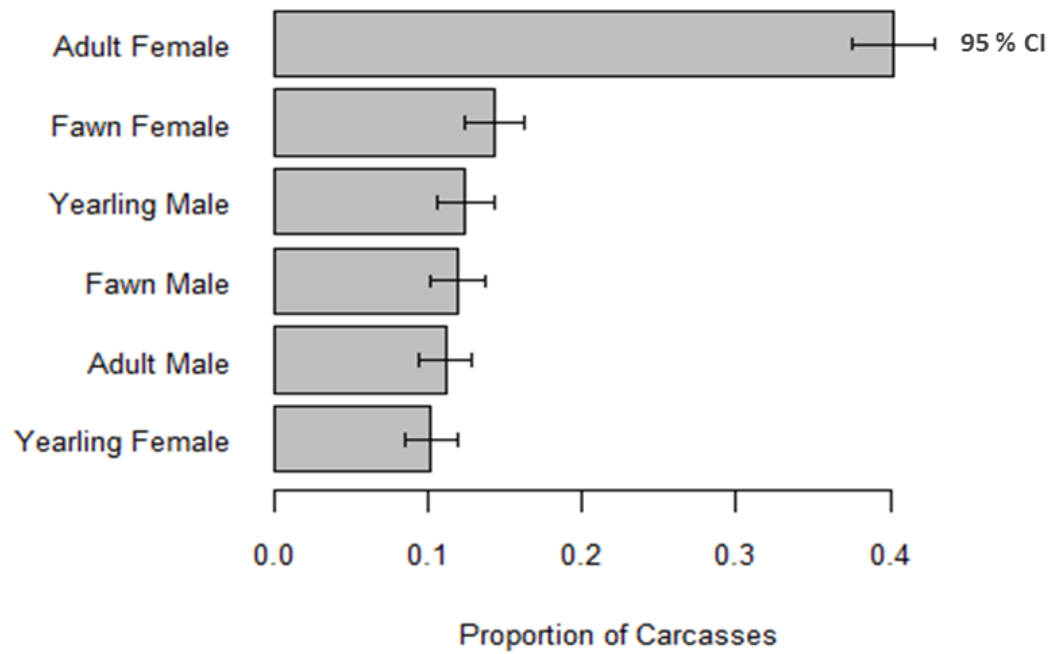


Figure 3.2. The proportion of carcasses in each mule deer demographic group that was involved in vehicle collisions in Utah.

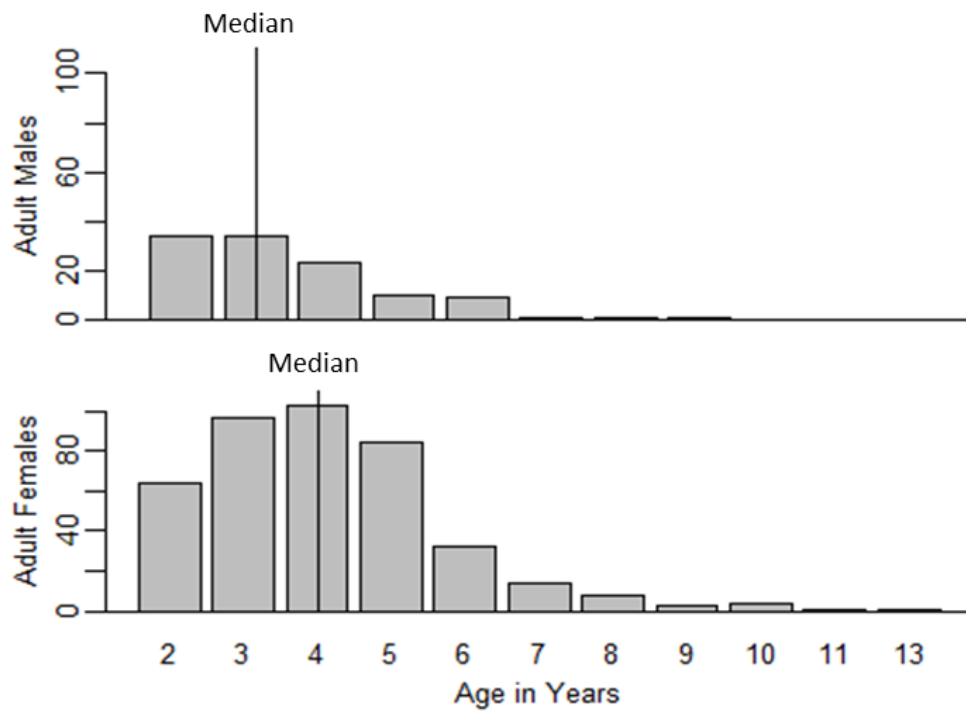


Figure 3.3. Age estimates of adult female and adult male mule deer that were killed in vehicle collisions in Utah.

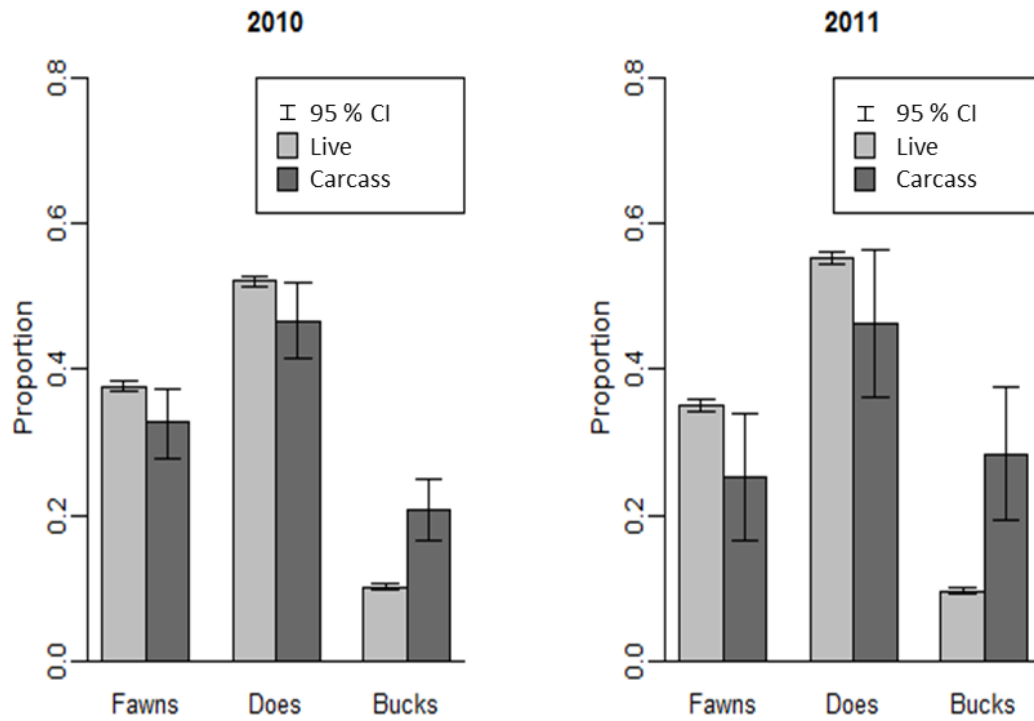


Figure 3.4. A comparison bucks, does, and fawns in carcass surveys to those in classification surveys of live deer for fall 2010 and fall 2011 in Utah.

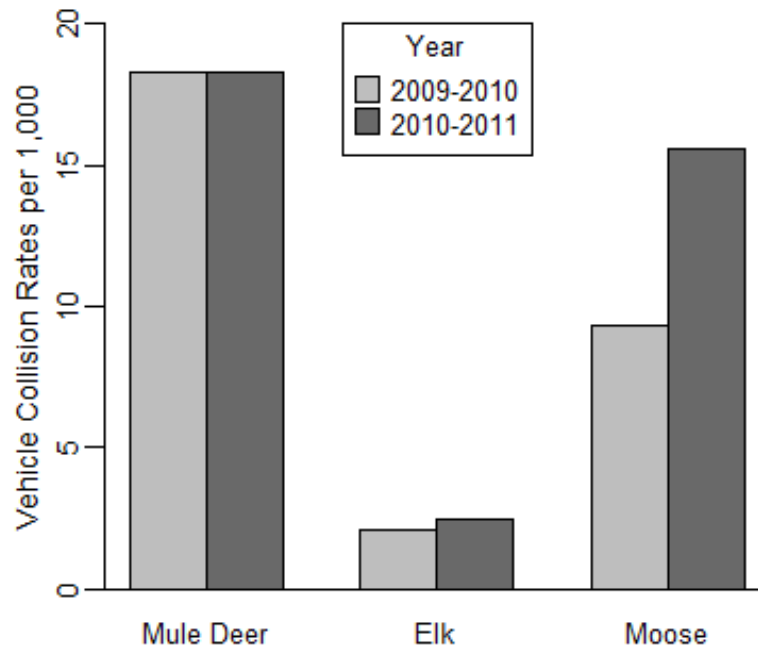


Figure 3.5. Vehicle collision rates (per 1,000 individuals) for mule deer, elk, and moose in Utah for 2009-2010 and 2010-2011.

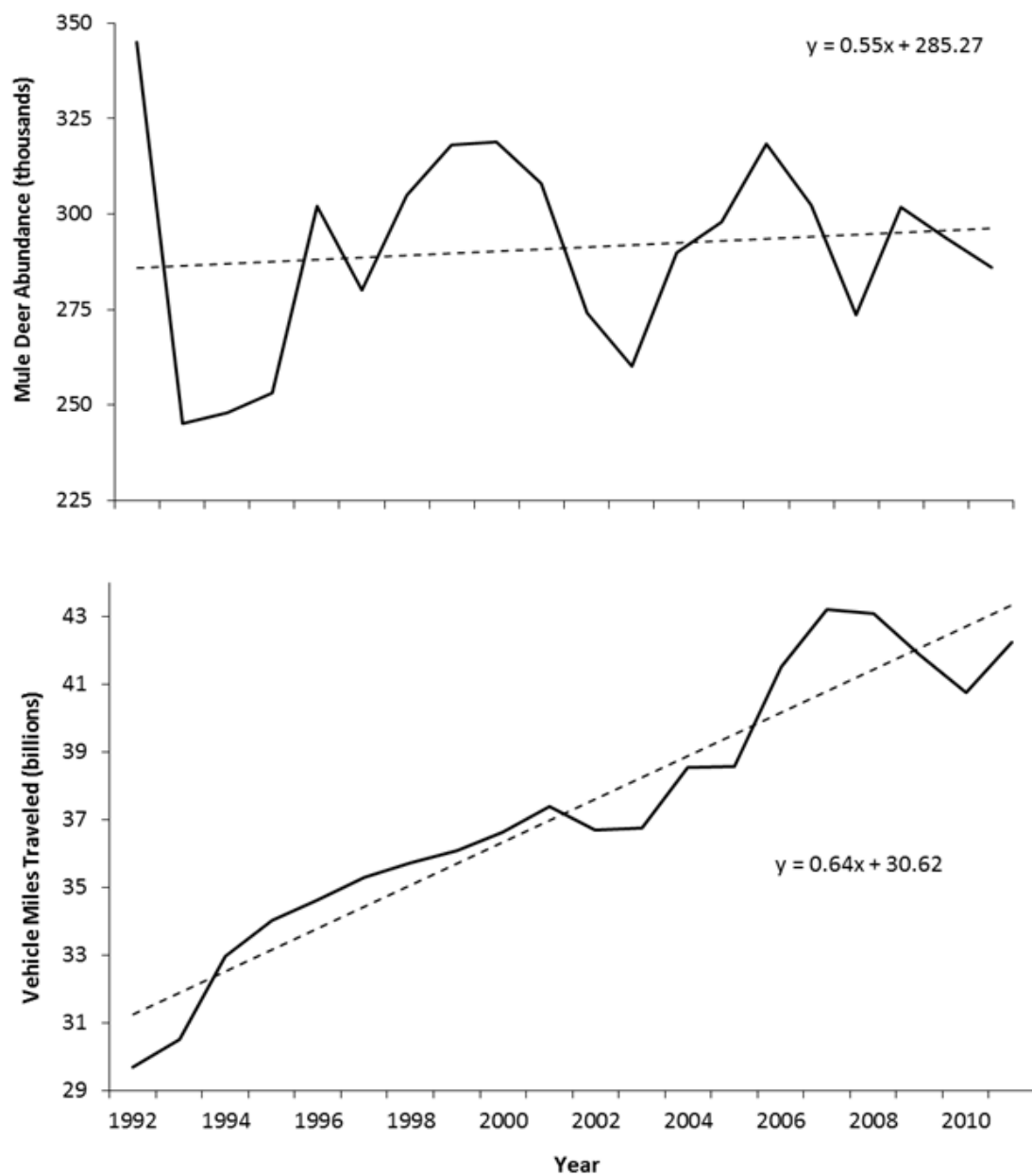


Figure 3.6. Mule deer abundance and traffic volume (vehicle miles traveled) estimates in Utah for 1992-2011.

CHAPTER 4
THE EFFECT OF WINTER CLIMATE ON VEHICLE COLLISION RATES OF MULE
DEER

ABSTRACT

Understanding how deer move in relationship to roads is critical, because deer appear to be especially prone to vehicle collisions, and collisions cause vehicle damage, deer death, 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, I analyzed mule deer movements during two consecutive winter seasons to determine what effect climate had on deer-vehicle collision rates. I used meteorological data from local weather stations to describe temperature, precipitation, and snow depth. I monitored deer movements with GPS telemetry to document distance of deer to roads, elevation use, and road crossing rates. I also documented changes in deer abundance and traffic volumes, which were potentially confounding variables. I found that precipitation and snow depth differed considerably between winters, with precipitation decreasing 50 % and snow depth decreasing 48 % during the second winter. In response, deer used habitats that were 16 % higher in elevations and 55 % farther from roads. Daily crossing rates also decreased as much as 96 % on roads with high traffic volumes during the second winter. Reduced crossing rates were likely responsible for much of the 75 % decrease in deer-vehicle collisions occurred during the second winter. Deer survival was negatively correlated with crossing rates on the highest traffic volume road in the study area. It is unlikely that changes in deer abundance and traffic volumes were major drivers of variation in deer-vehicle collisions, because traffic volumes did not change between years and deer abundance only decreased 7 % the second winter. My data suggests a causal mechanism by which variation in winter conditions can contribute to differences in deer-vehicle collision rates between years.

INTRODUCTION

Understanding how deer (Cervidae) move in relationship to roads is critical for wildlife and transportation management, because deer are frequently involved in vehicle collisions throughout much of the developed world (Bruinderink and Hazebroek 1996, Conover 2001, Noro 2010). In the United States alone it has been estimated that 1-2 million vehicle collisions with large animals occur each year 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). Summer ranges are often farther from roads (Stewart et al. 2010). In early to late fall, mule deer generally move from high elevation ranges, largely in response to seasonally declining resource quality, as well as 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 south 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 as result deer are often closer to roads with high traffic volumes during winter (Reed 1981).

Mule deer movements may vary annually as well (Russell 1932). 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 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 roads with high traffic volumes.

Variation in movement patterns of deer can also produce marked changes in DVCs (Mysterud 2004, Sullivan 2011). A common 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 between years in response to changes in winter conditions.

Deer-vehicle collision rates are not only affected by movement patterns of deer but also by deer abundance and traffic volumes on roads (Jahn 1959, Sullivan 2011). For example, collision rates have been shown to be associated with abundance for both elk (*Cervus elaphus*) and mule deer (Romin and Bissonette 1996, 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 (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 1996). Alternatively, roads with low traffic volumes appear to have a limited effect on deer survival, even if deer 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. In this paper, I analyzed mule deer movements during two consecutive winter seasons to determine what effect climate had on DVC rates. I monitored deer movements to document road crossing rates, distance of deer to roads, and elevation use during both winters. I used meteorological data from local weather stations to describe temperature, precipitation, and snow depth in the study area. I also documented changes in deer abundance and traffic volumes, which were potentially confounding variables.

METHODS

Study area

The study area (8,278 km²) was located on the western edge of the Rocky Mountains in central Utah (Fig. 4.1). Topography in this area was mountainous and highly variable (1,463-3,415 m). The climate was temperate; typically 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 the eastern edge of the study area encompassed a small portion of the Colorado Plateau (Griffith and Omernik 2009). A variety of land cover types (> 40) existed within the study area, but aspen (*Populus tremuloides*), Gambel oak (*Quercus gambelii*), and sagebrush (*Artemisia* spp.) cover types were relatively common (Lowry et al. 2005). Mule deer, elk (*Cervus elaphus*) and a limited number of moose (*Alces alces*) occurred within the study area (Bernales et al. 2011).

Roads were common throughout the study area (Fig. 4.1), but the majority of the area was rural with low (< 500 vehicles/day) traffic volumes. However, there were a number of roads that had higher traffic volumes. For example US 6, a major east-west route in Utah, bisected the center of the study area (Fig. 4.1). Traffic volumes on US 6 within the study area were generally > 6,000 vehicles/day and speed limits varied between 72-105 kph. In 2005, US 6 was documented to be the sixth most dangerous highway in the state for DVCs (Kassar and Bissonette 2005). To improve safety for motorists and deer, 4 wildlife crossing structures and 26 km of intermittent, exclusionary fencing (2.4 m high) have been installed on US 6 within the study area. Most mitigation was in place prior to this study. However, one wildlife crossing structure (MP 204) and ~6 km of wildlife fencing were installed during the study. Prior to installation, 6-7 % of deer carcasses reported during winter occurred within the section of highway (MP 202-205). Consequently, the project may have had a minor impact on the results reported in this paper.

Winter conditions

To document winter conditions, I obtained temperature, precipitation, and snow depth data from 12 weather stations that were located throughout the study area (Fig. 4.1). 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). I defined the winter season as 1 December-31 March. 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.

I 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, I used the nonparametric Wilcoxon rank-sum test ($\alpha = 0.05$). I used the same approach for all comparisons in the paper, except for DVC data. When I compared differences in DVC data between winters, I

used Chi-square tests ($\alpha = 0.05$). All statistical tests for this for this study were performed in R 2.14 (R Development Core Team 2012). I purposely kept the statistics simple as per Guthery (2008).

Traffic volumes and deer abundance

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

Mule deer abundance was estimated annually by the UDWR using a combination of ground and aerial counts for deer management units throughout the state; however, no measures of uncertainty were reported for abundance estimates (Bernales et al. 2011). I used management unit totals to estimate the number of mule deer within my study area by weighting totals by the proportion of the management unit area that occurred within the boundaries of my study area.

Deer movements and survival

To document the movements and survival of deer in relationship to roads, 32 adult (> 2 yrs) female mule deer were captured on winter ranges in the US 6 corridor near Diamond Fork, Sheep Creek, Colton, and Gordon Creek (Fig. 4.1). Contractors employed by the Utah Division of Wildlife Resources captured deer using a standard helicopter and net gun technique (Krausman and Hervert 1985), but one additional study animal was captured by UDWR biologists using chemical immobilization (Eberhardt et al. 1984). All deer were captured and handled in

accordance with guidelines for the use of mammals in research (Sikes and Gannon 2011), under permits that were held by the UDWR. Captured deer were instrumented with store-on-board GPS tracking collars with remote-download capability (Model 4400s, Lotek Wireless inc., Newmarket, Ontario, Canada). I programmed collars to record one location every 8 hours and to drop-off after 1.5 years when GPS battery life had been exhausted. Each tracking collar was also equipped with a VHF transmitter and mortality sensor. I monitored survival of deer weekly and examined carcasses of deceased animals to determine cause-specific mortality (Peterson and Messmer 2011)

All GPS locations for deer were screened for accuracy and improbable movement locations were removed (Villepique et al. 2008). I estimated Daily Road Crossing (DRC) rates for each study animal by overlaying the animal's movement path on the road network in the study area. A current roads layer for the study area was obtained from the Utah Automated Geographic Research Center (Utah AGRC 2012). The DCR analysis was performed in ArcGIS 10.1 (ESRI, Redlands, California, USA) using the intersect tool. The reported DCR estimates are conservative and represent the minimum number of road crossings because the interval between fixes was long enough that deer could have moved back and forth across roads without being detected.

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

I estimated survival rates for deer using a known-fate analysis in Program Mark 6.1 (White and Burnham 1999). I fit models with DRC rates, distance to roads, and year, and compared them to an intercept only model using 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, I considered the model with an additional parameter as noncompeting (Arnold 2010).

Deer-vehicle collisions

To estimate the number of DVCs within my study area, I used carcass survey data that were collected by UDOT contractors. Carcass surveys have been conducted on a number of roads throughout Utah since at least 1998 (Bissonette and Rosa 2012). Carcass surveys were performed using automobiles that were driven at posted speed limits by a single observer. If the road had multiple traffic lanes, the survey automobile was driven in the slow lane, nearest to the shoulder of the road. Undivided roads were surveyed in only one direction, while divided roads with a median were surveyed in both directions. During surveys, observers were required to remove all carcasses that were detected on the road surface, the median, and the road shoulder out to the reflective highway markers. Observers kept detailed records of the species removed and their locations. Location data were recorded as both the highway and nearest mile marker, and as GPS coordinates recorded with a Garmin eTrex L Legend H unit (Garmin, Olathe, Kansas, USA). Within my study area, carcass surveys were conducted on US 6 and all major roads. DVC estimates from carcass surveys represent minimum estimates, because carcass survey totals have not been corrected for bias (Olson et al. 2013a, in preparation). Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

RESULTS

Winter conditions

Climate data on winter conditions were collected from 12 weather stations throughout the study area (Fig. 4.1). Mean elevation of weather stations was 2,484 m ($n = 12$, $SD = 293$). The

long-term (1981-2012) mean winter temperature for the study area was -4.9°C ($n = 384$, $SD = 8.4$). For total precipitation (1981-2012) and daily snow depth (2003-2012), the long-term means were 226 mm ($n = 384$, $SD = 52$) and 891 mm ($n = 50$, $SD = 359$) respectively. Winter 2010-11 was 18 % warmer than average and winter 2011-12 was 41 % warmer (Fig. 4.2). Mean monthly temperature differed between winters ($t[10] = -11.89$, $p = < 0.01$), and winter 2011-12 was 28% warmer. Precipitation also differed between winters ($t[7] = 3.16$, $p = 0.02$) with 50 % less precipitation occurring in winter 2011-12. Precipitation during winter 2010-11 was 20% above average and winter 2011-12 was 41 % below average. Mean snow depth was also significantly different between the two winters ($t[5] = 9.76$, $p = < 0.01$), and depths were 48 % less in winter 2011-12. Snow depth during winter 2010-11 was 31 % above average and winter 2011-12 was 32 % below average (Fig. 4.2).

Traffic volumes and deer abundance

Traffic volumes on US 6 ($t[12] = 0.11$, $p = 0.92$) and major roads ($t[61] = -0.32$, $p = 0.75$) did not differ significantly between years (Fig. 4.3). Mean traffic volume for US 6 was 9,216 vehicles/day ($n = 27$, $SD = 1,965$) and for major roads it was 3,625 vehicles/day ($n = 124$, $SD = 3,214$).

The long-term (2007-2012) mean abundance of mule deer in the study area was 30,262 individuals ($n = 6$, $SD = 3,045$) and for the state of Utah (1992-2012) it was 292,353 individuals ($n = 21$, $SD = 26,383$). Deer abundance in the study area was 3 % above average during winter 2010-11 and 4 % below average during 2011-12 (Fig. 4.4). According to population estimates, deer abundance decreased 7 % between winter 2010-11 and winter 2011-12. In Utah, deer abundance was 1 % above average in 2010-11 and 2 % below average in 2011-12. The statewide deer population decreased 3 % between years. Abundance data, however, should be interpreted

with caution because sampling variance was not estimated and counts of wildlife generally have considerable uncertainty.

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. 4.1). The mean distance of deer capture locations to US 6 was 3.5 km ($n = 32$, $SD = 3.9$ km). GPS collar performance during the study was adequate with a fix rate of 89 %. The percentage of 3D locations was 87 %, indicating horizontal location error was generally < 20 m (Di Orio et al. 2003, Sawyer et al. 2009)

From GPS telemetry data, I estimated that deer crossed roads a minimum of 1,829 times during winter 2010-11 and 1,600 times during winter 2011-12. Most road crossings (95 %) were on minor roads and only 3 % were on major roads and 2 % were on US 6. Daily crossing rate on all roads decreased 59 % percent between winters. However, the difference between winters by road type was only significant for US 6 ($W = 663$, $p < 0.01$), but not for major roads ($W = 464$, $p = 0.56$) or minor roads ($W = 462.5$, $p = 0.81$). The decrease in DCR on US 6 was 96 % (Fig. 4.5).

In addition to differences in crossing rates, there were also differences in habitat use. Elevation use differed between winters ($t[12] = 0.11$, $p < 0.01$) with deer occurring at elevations that were 16 % higher during winter 2011-12 (Fig. 4.6). Deer also occurred 55 % farther from all roads during the second winter, but distance varied by road type. Deer were 213 % farther from US 6, 21 % farther from major roads, 42 % farther from minor roads during winter 2011-12 (Fig. 4.7). The distance that deer occurred from US 6 ($W = 112.0$, $p < 0.01$) and major roads ($W = 301.5$, $p < 0.01$) differed significantly between winters, but I did not detect a difference for minor roads ($W = 415.0$, $p = 0.36$).

During the first winter (2010-11), 2 study animals died. One deer was killed as result of a vehicle collision on US 6. The cause of death for the second animal was unclear because the animal's remains were not located until ~14 days after it had died due to a dysfunctional VHF transmitter. When the carcass was finally recovered, it was located 75 m from US 6 and had been cached by a cougar (*Puma concolor*). I do not know if this animal was killed by a cougar or if the animal was killed in a vehicle collision, and the remains were scavenged by a cougar (Bauer et al. 2005). No study animals died during the second winter (2011-12).

When I modeled deer survival for covariate and year effects, I found that daily crossing rate on US 6 was the top predictor of deer survival (Table 4.1). According to model predictions, crossing rates > 0.2 began to substantially reduce deer survival (Fig. 4.8); although there was considerable uncertainty in survival estimates due to small sample size and the fact that few deer died. Crossing rates of minor roads also had significant support (Table 4.1), but 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 DVCs within our study area decreased 75 % on monitored roads between 2010-11 and 2011-12. The number of DVCs on US 6 ($\chi^2 [1, n = 202] = 139.7, p = < 0.01$) and major roads ($\chi^2 [1, n = 185] = 23.7, p = < 0.01$) differed significantly between winters. Deer-vehicle collisions decreased 91 % on US 6 and 52 % on major roads during winter 2011-12 (Fig. 4.9). Additionally, DVCs in Utah ($\chi^2 [1, n = 2,278] = 760.3, p = < 0.01$) differed between winters with 73 % fewer DVCs occurring in winter 2011-12.

DISCUSSION

Deer-vehicle collisions are a significant management and conservation challenge in landscapes that have been altered by humans (Neumann et al. 2012). The rate at which DVCs occur is spatially and temporally variable (Biggs et al. 2004, Kassir 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. My purpose in conducting this study was to examine how natural variation in climate during winter influenced deer distribution, movement patterns, and DVC rates.

The study encompassed two consecutive winters in which climatic 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 567 mm lower during the second winter. Mule deer 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.

Movement allows deer to adjust to environmental variation in snow depth (Garrott et al. 1987, Brown 1992). In my study, deer wintered at higher elevations during the second winter possibly due to 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 my study area, deer that crossed US 6 less often had higher survival than deer that crossed more frequently. Additionally, relatively low road crossing rates (1.4 crossings/week) 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 I 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 climate caused much of the difference in DVCs I observed between winters, DVC rates may have also been affected by changes in traffic volumes (Romin and Bissonette 1996). 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 I 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, Bernalles 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, which is less than the 52 % decrease in DVCs I observed on major roads and the 91 % decrease I observed on US 6. Based on experimental evidence conducted on white-tailed deer (DeNicola and Williams 2008), I would expect DVCs to decrease proportionally to changes in deer abundance, which did not occur in my study. Additionally, some of the variability in abundance estimates between winters may have been the result of deer being more difficult to detect during surveys because snow cover was sparse and deer were more dispersed during the second winter (Habib et al. 2012). Due to these factors, I suggest that changes in deer abundance may have had a marginal effect on DVC rates but was not the major driver of the pattern that was observed.

Snow conditions, which can vary considerably between years, are a major factor influencing the movement patterns of mule deer in temperate climates (Garrott et al. 1987). More than 30 years ago, Reed and Woodard (1981) suggested winter conditions were likely an important driver of DVC rates. The evidence from this study provides a causal 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.

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 the increased probability of 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. Permanent warning signs are often placed in areas with high DVCs (Jahn 1959); however, their effectiveness can diminish as drivers become accustomed to them (Putman 1997). Temporary signs, however, appear to be more effective (Sullivan et al. 2004). Following this logic, 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. 2013b, in preparation). 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. Fundamentally, a warning system such as this could accurately represent the spatial and temporal variation that occurs in DVC patterns, which could improving driver safety and reduce the number of deer that are killed.

LITERATURE CITED

- Akaike, H. 1973. Maximum likelihood identification of Gaussian autoregressive moving average models. *Biometrika* 60:255–265.
- Allen, R. E., and D. R. McCullough. 1976. Deer-car accidents in southern Michigan. *Journal of Wildlife Management* 40:317–325.
- Arnold, T. W. 2010. Uninformative parameters and model selection using Akaike's information criterion. *Journal of Wildlife Management* 74:1175–1178.
- Austin, D. D. 2010. *Mule deer: a handbook for Utah hunters and landowners*. Utah State University Press, Logan, Utah, USA.
- Bauer, J. W., K. A. Logan, L. L. Sweanor, W. M. Boyce, and C. A. Jones. 2005. Scavenging behavior in puma. *The Southwestern Naturalist* 50:466–471.
- Bernales, H. H., K. R. Hersey, and A. Aoude. 2011. *Utah big game annual report 2011*. Utah Division of Wildlife Resources, Salt Lake City, Utah, USA.
- Biggs, J., S. Sherwood, S. Michalak, L. Hansen, and C. Bare. 2004. Animal-related vehicle accidents at the Los Alamos National Laboratory, New Mexico. *The Southwestern Naturalist* 49:384–394.
- Bissonette, J. A., and W. Adair. 2008. Restoring habitat permeability to roaded landscapes with isometrically-scaled wildlife crossings. *Biological Conservation* 141:482–488.
- Bissonette, J. A., C. A. Kassar, and J. C. Cook. 2008. Assessment of costs associated with deer-vehicle collisions: human death and injury, vehicle damage, and deer loss. *Human-Wildlife Conflicts* 2:17–27.
- Bissonette, J. A., and S. Rosa. 2012. An evaluation of a mitigation strategy for deer-vehicle collisions. *Wildlife Biology* 18:414–423.

- Boeker, E. L., V. E. Scott, H. G. Reynolds, and B. A. Donaldson. 1972. Seasonal food habits of mule deer in Southwestern New Mexico. *Journal of Wildlife Management* 36:56–63.
- Brown, C. G. 1992. Movement and migration patterns of mule deer in southeastern Idaho. *Journal of Wildlife Management* 56:246–253.
- Bruinderink, G. W. T. A., and E. Hazebroek. 1996. Ungulate traffic collisions in Europe. *Conservation Biology* 10:1059–1067.
- Burnham, K. P., and D. R. Anderson. 2002. *Model Selection and Multi-Model Inference: A Practical Information-Theoretic Approach*. Springer, New York, New York, USA.
- Case, R. M. 1978. Interstate highway road-killed animals: a data source for biologists. *Wildlife Society Bulletin* 6:8–13.
- Conover, M. R., W. C. Pitt, K. K. Kessler, T. J. DuBow, and W. A. Sanborn. 1995. Review of human injuries, illnesses, and economic losses caused by wildlife in the United States. *Wildlife Society Bulletin* 23:407–414.
- Conover, M. R. 2001. *Resolving Human-Wildlife Conflicts: The Science of Wildlife Damage Management*. CRC Press, Boca Raton, Florida, USA.
- DeNicola, A. J., and S. C. Williams. 2008. Sharpshooting suburban white-tailed deer reduces deer-vehicle collisions. *Human-Wildlife Interactions* 2:28–33.
- Eberhardt, L. E., E. E. Hanson, and L. L. Cadwell. 1984. Movement and activity patterns of mule deer in the sagebrush-steppe region. *Journal of Mammalogy* 65:404–409.
- Garrott, R. A., G. C. White, R. M. Bartmann, L. H. Carpenter, and A. W. Alldredge. 1987. Movements of female mule deer in northwest Colorado. *Journal of Wildlife Management* 51:634–643.
- Gilbert, P. F., O. C. Wallmo, and R. B. Gill. 1970. Effect of snow depth on mule deer in Middle Park, Colorado. *Journal of Wildlife Management* 34:15–23.

- Griffith, G. E., and J. M. Omernik. 2009. Ecoregions of Utah (EPA). Environmental Information Coalition, Washington, D.C., USA. [online] URL:
[http://www.eoearth.org/article/Ecoregions_of_Utah_\(EPA\)](http://www.eoearth.org/article/Ecoregions_of_Utah_(EPA))
- Grovenburg, T., J. Jenks, R. Klaver, K. Monteith, D. Galster, R. Shauer, W. Morlock, and J. Delger. 2008. Factors affecting road mortality of whitetailed deer in eastern South Dakota. *Human–Wildlife Interactions* 2:48–59.
- Gruell, G. E., and N. J. Papez. 1963. Movements of mule deer in northeastern Nevada. *Journal of Wildlife Management* 27:414.
- Guthery, F. S. 2008. Statistical ritual versus knowledge accrual in wildlife science. *Journal of Wildlife Management* 72:1872–1875.
- Habib, T. J., D. A. Moore, and E. H. Merrill. 2012. Detection and stratification approaches for aerial surveys of deer in prairie–parklands. *Wildlife Research* 39:593–602.
- Hansen, L. A., J. Biggs, K. D. Bennett, C. Bare, and S. Sherwood. 2012. Life in the fast lane: road crossing behavior of mule deer in a wildland-urban interface. Los Alamos National Laboratory, Los Alamos, New Mexico, USA.
- Huijser, M. P., P. T. McGowen, J. Fuller, A. Hardy, and A. Kociolek. 2008. Wildlife-vehicle collision reduction study: report to Congress. Western Transportation Institute, Bozeman, Montana, USA.
- Jahn, L. R. 1959. Highway mortality as an index of deer-population change. *Journal of Wildlife Management* 23:187–197.
- Kassar, C. A., and J. A. Bissonette. 2005. Deer-vehicle crash hotspots in Utah: data for effective mitigation. Utah State University, Logan, Utah, USA.

- Kie, J. G., and B. Czech. 2000. Mule and black-tailed deer. Pages 629–657 in S. Demarais and P. R. Krausman, editors. *Ecology and management of large mammals in North America*. Prentice Hall, Upper Saddle River, New Jersey, USA.
- Krausman, P. R., and J. J. Hervert. 1985. Capturing deer and mountain sheep with a net-gun. *Journal of Wildlife Management* 13:71–73.
- Kucera, T. E. 1992. Influences of sex and weather on migration of mule deer in California. *Great Basin Naturalist* 52:122–130.
- Langley, R. L., S. A. Higgins, and K. B. Herrin. 2006. Risk factors associated with fatal animal-vehicle collisions in the United States, 1995–2004. *Wilderness & Environmental Medicine* 17:229–239.
- Litvaitis, J. A., and J. P. Tash. 2008. *An approach toward understanding wildlife-vehicle collisions*. Environmental Assessment 42:688–697.
- Lowry, J. H., R. D. Ramsey, K. Boykin, P. Comer, S. Falzarano, W. Kepner, J. Kirby, L. Langs, J. Prior-Magee, G. Manis, L. O'Brien, T. Sajwaj, K. A. Thomas, W. Rieth, S. Schrader, D. Schrupp, K. Schulz, B. Thompson, C. Velasquez, C. Wallace, E. Waller, and B. Wolk. 2005. *Southwest Regional Gap Analysis Project: final report on land cover mapping methods*. RS/GIS Laboratory, Utah State University, Logan, Utah, USA.
- Mastro, L., M. Conover, and S. N. Frey. 2008. Deer–vehicle collision prevention techniques. *Human–Wildlife Interactions* 2:80–92.
- McCollister, M. F., and F. T. Van Manen. 2010. Effectiveness of wildlife underpasses and fencing to reduce wildlife-vehicle collisions. *Journal of Wildlife Management* 74:1722–1731.
- Myserud, A. 2004. Temporal variation in the number of car-killed red deer *Cervus elaphus* in Norway. *Wildlife Biology* 10:203–211.

- NCDC. 2013. Climate data online. National Climatic Data Center. [online] URL:
www.ncdc.noaa.gov/cdo-web/
- Neumann, W., G. Ericsson, H. Dettki, N. Bunnefeld, N. S. Keuler, D. P. Helmers, and V. C. Radeloff. 2012. Difference in spatiotemporal patterns of wildlife road-crossings and wildlife-vehicle collisions. *Biological Conservation* 145:70–78.
- Ng, J. W., C. Nielsen, and C. C. St. Clair. 2008. Landscape and traffic factors influencing deer-vehicle collisions in an urban environment. *Human-Wildlife Conflicts* 2:34–47.
- Noro, M. 2010. Analysis of deer ecology and landscape features as factors contributing to deer-vehicle collisions in Hokkaido, Japan. Transportation Research Board, Washington, D.C., USA.
- NWCC. 2013. Snotel data. National Water and Climate Center. [online] URL:
<http://www.wcc.nrcs.usda.gov/>
- Olson, D. D., J. A. Bissonette, and D. C. Coster. 2013a. How many deer are really being killed in vehicle collisions? *In Preparation*.
- Olson, D. D., J. A. Bissonette, P. C. Cramer, A. D. Green, P. J. Scott, and D. C. Coster. 2013b. Monitoring wildlife-vehicle collisions in the information age: how smartphones can improve data collection. *In Preparation*.
- Di Orio, A. P., R. Callas, and R. J. Schaefer. 2003. Performance of two GPS telemetry collars under different habitat conditions. *Wildlife Society Bulletin* 31:372–379.
- Parker, K. L., C. T. Robbins, and T. A. Hanley. 1984. Energy expenditures for locomotion by mule deer and elk. *Journal of Wildlife Management* 48:474–488.
- Peterson, C., and T. A. Messmer. 2007. Effects of winter-feeding on mule deer in northern Utah. *Journal of Wildlife Management* 71:1440–1445.

- Peterson, C., and T. A. Messmer. 2011. Biological consequences of winter-feeding of mule deer in developed landscapes in northern Utah. *Wildlife Society Bulletin* 35:252–260.
- Putman, R. J. 1997. Deer and road traffic accidents: options for management. *Journal of Environmental Management* 51:43–57.
- R Development Core Team. 2012. R: *A language and environment for statistical computing, reference index version 2.14.12*. R Foundation for Statistical Computing, Vienna, Austria. [online] URL: <http://www.R-project.org>.
- Reed, D. F., and T. N. Woodard. 1981. Effectiveness of highway lighting in reducing deer-vehicle accidents. *Journal of Wildlife Management* 45:721–726.
- Reed, D. F. 1981. Conflicts with civilization. Pages 509–545 in O. C. Walmo, editor. *Mule and black-tailed deer of North America*. University of Nebraska Press, Lincoln, Nebraska, USA.
- Romin, L. A., and J. A. Bissonette. 1996. Temporal and spatial distribution of highway mortality of mule deer on newly constructed roads at Jordanelle Reservoir, Utah. *Western North American Naturalist* 56:1–11.
- Russell, C. P. 1932. Seasonal migration of mule deer. *Ecological Monographs* 2:1–46.
- Sawyer, H., R. M. Nielson, F. Lindzey, and L. L. McDonald. 2006. Winter habitat selection of mule deer before and during development of a natural gas field. *Journal of Wildlife Management* 70:396–403.
- Sawyer, H., M. J. Kauffman, R. M. Nielson, and J. S. Horne. 2009. Identifying and prioritizing ungulate migration routes for landscape-level conservation. *Ecological Applications* 19:2016–2025.

- Sawyer, H., M. J. Kauffman, A. D. Middleton, T. A. Morrison, R. M. Nielson, and T. B. Wyckoff. 2013. A framework for understanding semi-permeable barrier effects on migratory ungulates. *Journal of Applied Ecology* 50:68–78.
- Schlaepfer, M. A., M. C. Runge, and P. W. Sherman. 2002. Ecological and evolutionary traps. *Trends in Ecology & Evolution* 17:474–480.
- Sikes, R. S., and W. L. Gannon. 2011. Guidelines of the American Society of Mammalogists for the use of wild mammals in research. *Journal of Mammalogy* 92:235–253.
- Stewart, K. M., R. T. Bowyer, J. G. Kie, and M. A. Hurley. 2010. Spatial distributions of mule deer and North American elk: resource partitioning in a sage-steppe environment. *The American Midland Naturalist* 163:400–412.
- Sullivan, J. M. 2011. Trends and characteristics of animal-vehicle collisions in the United States. *Journal of Safety Research* 42:9–16.
- Sullivan, T. L., A. F. Williams, T. A. Messmer, L. A. Hellinga, and S. Y. Kyrychenko. 2004. Effectiveness of temporary warning signs in reducing deer-vehicle collisions during mule deer migrations. *Wildlife Society Bulletin* 32:907–915.
- Thomas, T. R., and L. R. Irby. 1990. Habitat use and movement patterns by migrating mule deer in southeastern Idaho. *Northwest Science* 64:19–27.
- UCCW. 2009. Utah precipitation. Utah Center for Climate and Weather. [online] URL: http://utahweather.org/UWC/lightning_precipitation/precipitation.html
- UCCW. 2013. Climate of Utah: NWS description of Utah's climate. Utah Center for Climate and Weather. [online] URL: <http://utahweather.org/climatology/climate-of-utah/>
- UDOT. 2012. Traffic on Utah's highways. Utah Department of Transportation. [online] URL: <http://www.udot.utah.gov/>

Utah AGRC. 2012. Roads and highway system. Automated Geographic Reference Center.

[online] URL: <http://gis.utah.gov/>

Villepique, J. T., V. C. Bleich, B. M. Pierce, T. R. Stephenson, R. A. Botta, and R. T. Bowyer.

2008. Evaluating GPS collar error: a critical evaluation of Televilt POSREC-Science™ collars and a method for screening location data. *California Fish and Game* 94:155–168.

White, G. C., and K. P. Burnham. 1999. Program mark: survival estimation from populations of marked animals. *Bird Study 46 Supplement* 120–138.

Wood, P., and M. L. Wolfe. 1988. Intercept feeding as a means of reducing deer-vehicle collisions. *Wildlife Society Bulletin* 16:376–380.

Table 4.1. Models examining effects of various road-related covariates on mule deer survival in central Utah.

Model	Parameters	AICc	ΔAICc	AICc Weight
DCR US 6	2	23.72	0.00	0.275
DCR US 6 + Year	3	25.02	1.30	0.144
DCR Minor Roads	2	25.27	1.55	0.127
DCR US 6 + Dist. US 6	3	25.37	1.65	0.121
DCR US 6 + DCR Minor Roads	3	25.37	1.66	0.120
Distance Major Roads	2	26.89	3.17	0.056
DCR US 6 + Distance US 6 + Year	4	26.99	3.28	0.054
Distance Minor Roads	2	27.44	3.72	0.043
Distance US 6	2	28.58	4.86	0.024
Year	2	29.13	5.41	0.018
Intercept	1	29.88	6.16	0.013
DCR Major Roads	2	31.69	7.97	0.005

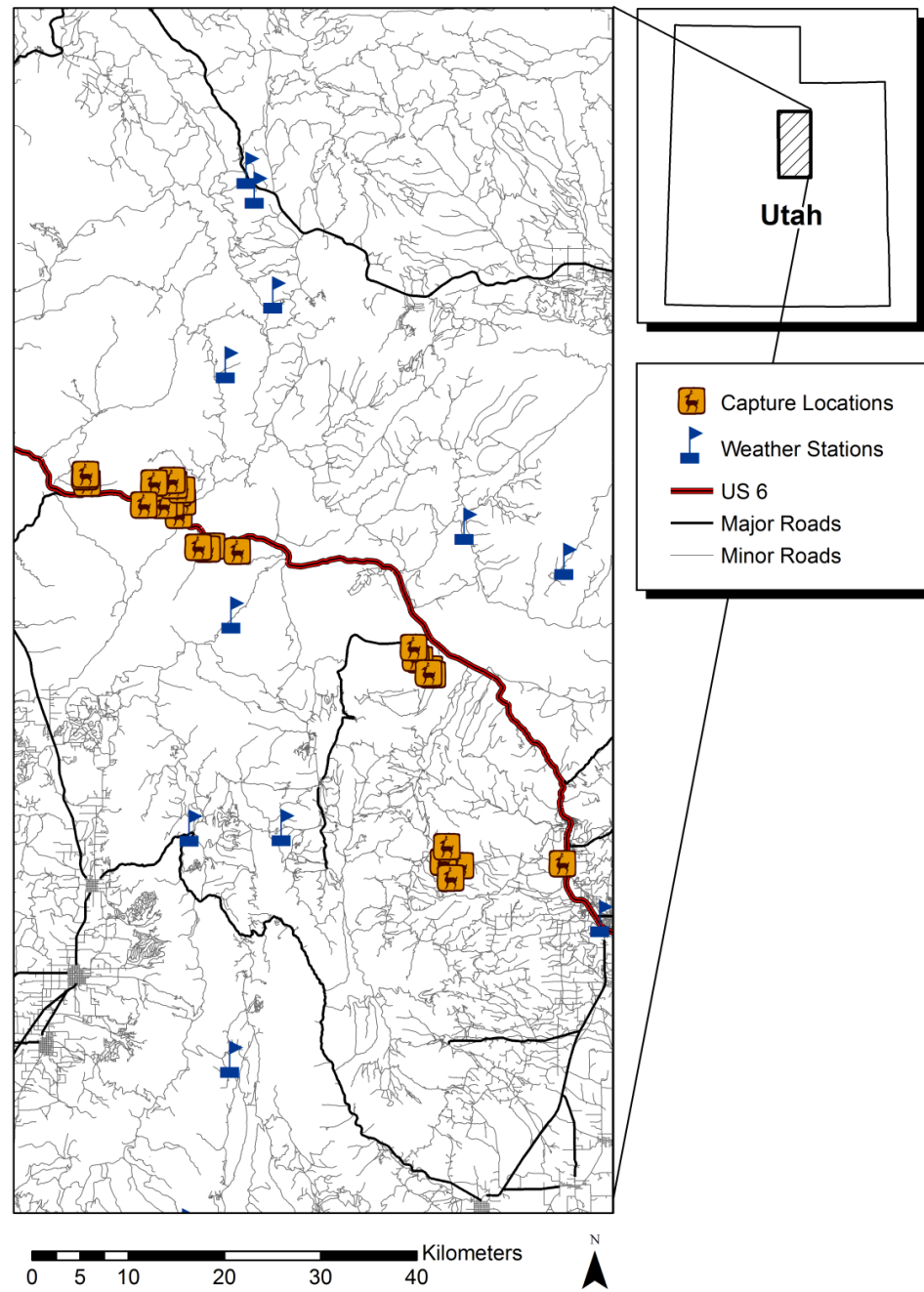


Fig. 4.1. Weather stations and mule deer capture locations in relationship to US 6 and other roads in central Utah.

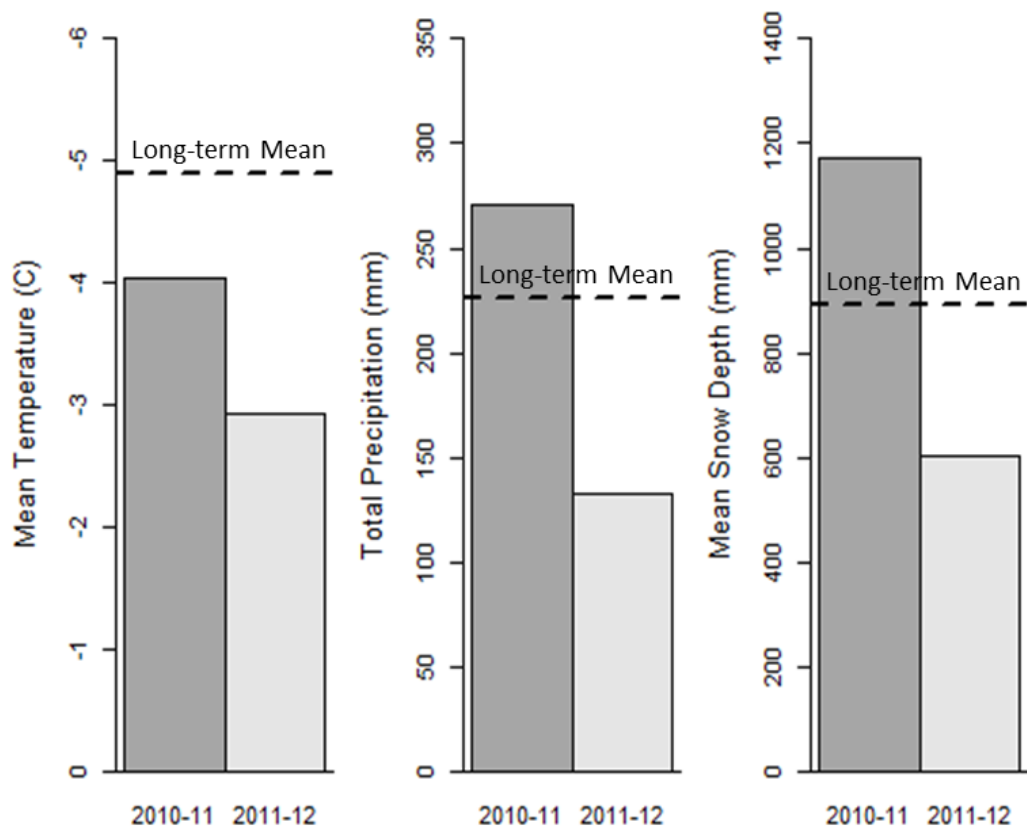


Fig. 4.2. Winter climate data collected from weather stations in central Utah.

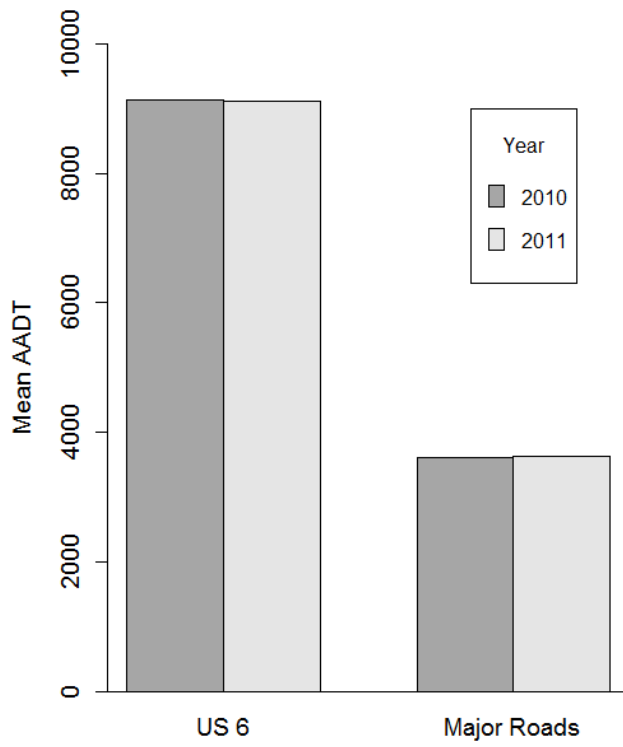


Fig. 4.3. Average Annual Daily Traffic (AADT) for US 6 and major roads in central Utah.

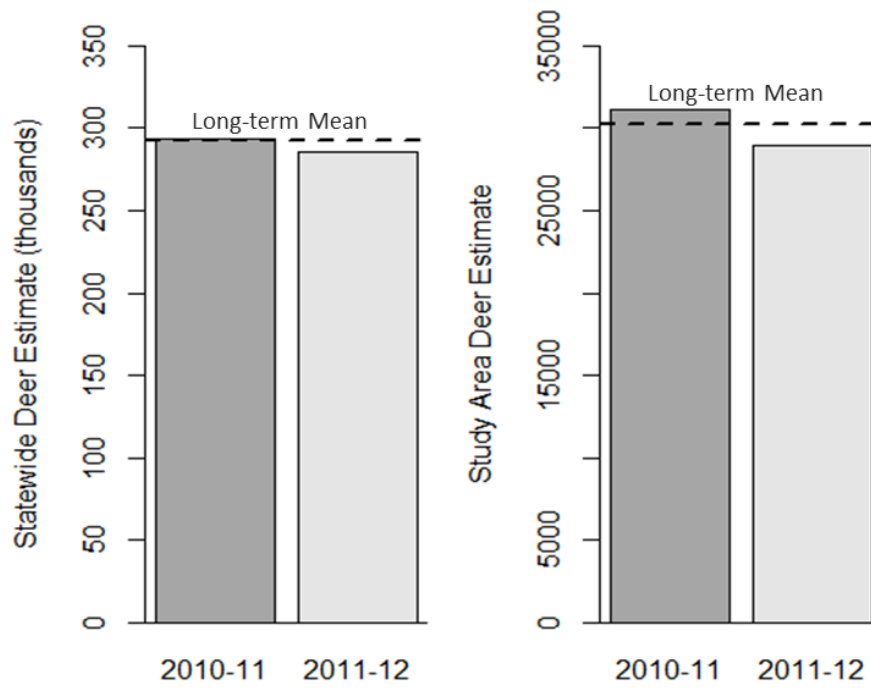


Fig. 4.4. Mule deer population estimates for the study area in central Utah and for the state of Utah.

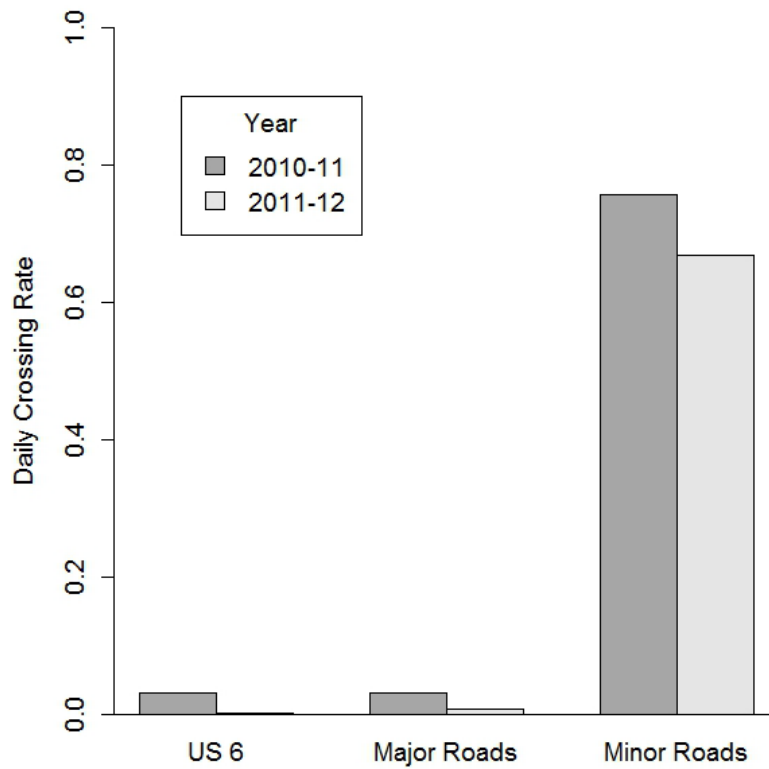


Fig. 4.5. Daily crossing rates of deer on US 6, major roads, and minor roads during winter 2010-11 and 2011-12.

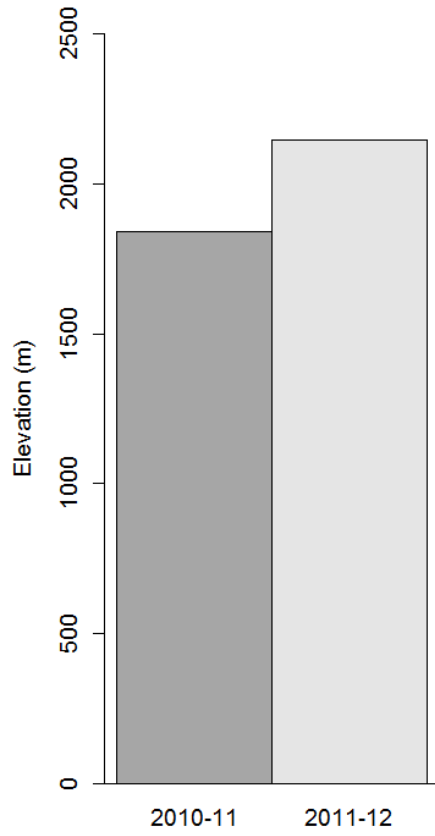


Fig. 4.6. Elevation use by deer during winter 2010-11 and 2011-12.

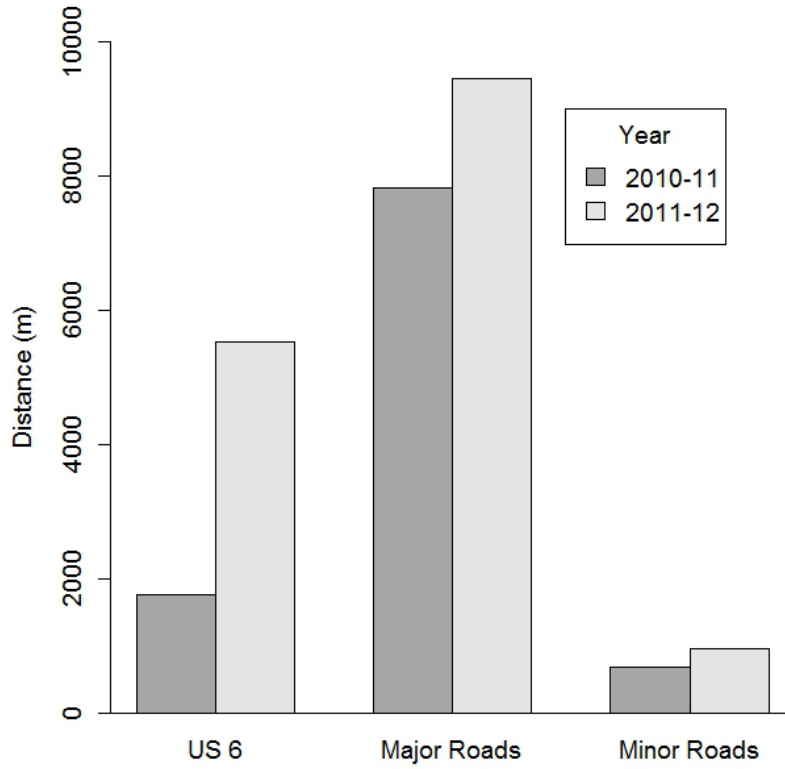


Fig. 4.7. Distance that deer occurred from US 6, major roads, and minor roads during winter 2010-11 and 2011-12.

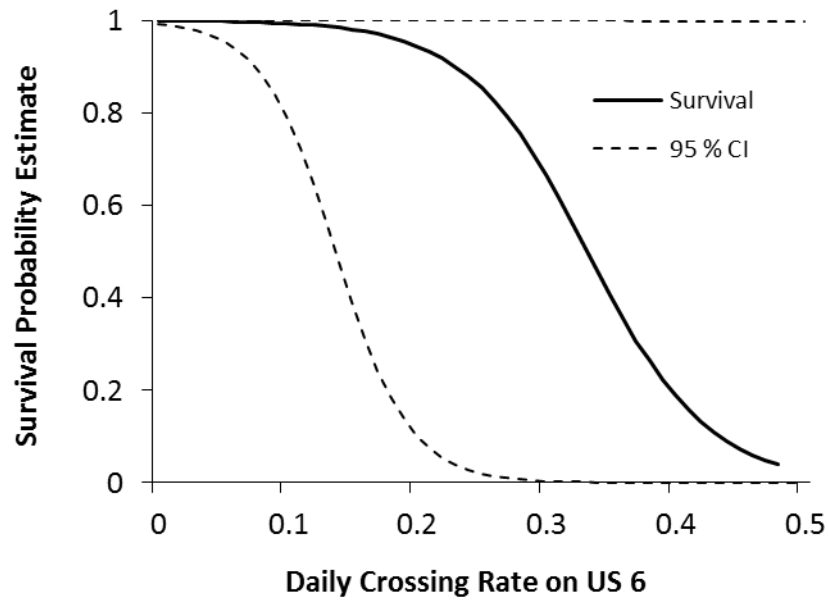


Fig. 4.8. The effect of US 6 crossing rate on survival estimates of mule deer.

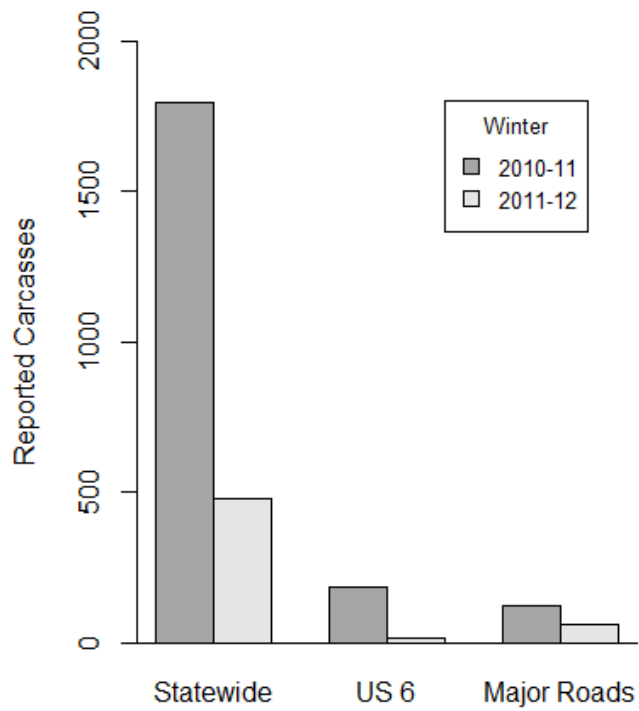


Figure 4.9. Deer-vehicle collision estimates for Utah, US 6, and major roads within the study area in central Utah.

CHAPTER 5

MONITORING WILDLIFE-VEHICLE COLLISIONS IN THE INFORMATION AGE: HOW SMARTPHONES CAN IMPROVE DATA COLLECTION¹

Abstract

Background: Currently there is a critical need for accurate and standardized wildlife-vehicle collision data, because it is the underpinning of mitigation projects that protect both drivers and wildlife. Gathering data can be challenging because wildlife-vehicle collisions occur over broad areas, during all seasons of the year, and in large numbers. Collecting data of this magnitude requires an efficient data collection system. Presently there is no widely adopted system that is both efficient and accurate.

Methodology/Principal Findings: My objective was to develop and test a smartphone-based system for reporting wildlife-vehicle collision data. The WVC Reporter system I developed consisted of a mobile web application for data collection, a database for centralized storage of data, and a desktop web application for viewing data. The smartphones that I tested for use with the application produced accurate locations (median error = 4.6-5.2 m), and reduced location error 99 % versus reporting only the highway/marker. Additionally, mean times for data entry using the mobile web application (22.0-26.5 s) were substantially shorter than using the pen/paper method (~60-90 s). I also found the pen/paper method had a data entry error rate of 10 % and those errors were virtually eliminated using the mobile web application. During the first year of use, 6,822 animal carcasses were reported using WVC Reporter. The desktop web application

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improved accesses to WVC data and allowed users to visualizing wildlife-vehicle collision patterns at both broad and fine scale extents.

Conclusions/Significance: The WVC Reporter integrated several modern technologies into a seamless method for collecting, managing, and using WVC data. As a result, the system vastly increased efficiency in reporting, improved accuracy, and enhanced visualization of data. The development costs for the system were minor when viewed in context of the potential benefits of having spatially accurate and temporally current wildlife-vehicle collision data.

Introduction

Wildlife-Vehicle Collisions (WVCs) are a global problem that impact both wildlife and motorists [1–5]. The sheer number of animals that are killed in vehicle-collisions is alarming; in the United States alone it has been estimated that ~1 million vertebrates are killed every day [6]. Wildlife-vehicle collisions involving large species, such as ungulates, can cause substantial vehicle damage and human injuries, and consequently they are a key public safety concern [7]. In the United States, there are 1-2 million vehicle collisions with large animals each year that result in 8.4 billion (USD) in damages [8]. Additionally, ~5 % of WVCs result in human injuries [7,8], and in the USA human fatalities resulting from WVCs have risen to ~200 annually [9].

Currently there is a critical need for accurate and standardized WVC data [10–12], because these are the foundation of mitigation projects that protect both motorists and wildlife [13]. For example, exclusionary fencing (> 2 m high) is used to prevent wildlife from accessing road right-of-ways, and it is typically only constructed on road sections with high traffic volumes and high numbers of WVCs [14]. Wildlife crossings, which promote connectivity and facilitate safe passage of wildlife above and below roads, are also placed in areas where WVCs occur [15–18]. Effective WVC mitigation is generally costly [19] and high quality WVC data helps ensure

that limited mitigation resources are strategically targeted to areas that produce the greatest results for motorists and wildlife. However, effectively gathering WVC data for mitigation planning has proven challenging [12] because WVCs occur over broad geographic areas, during all seasons of the year, and in large numbers [6,20]. Collecting data of this magnitude requires many observers and an efficient data management system.

Ecologists have been collecting WVC data since at least the 1920s [21]. These early ecologists recorded WVC data manually using the only method available to them at the time: pen and paper. Now almost a century later, most state agencies still use the pen/paper method to report animal carcasses that occur on roadways [12], which is problematic because data collected in this manner generally have low spatial accuracy (i.e. nearest highway and km/mi marker), contain avoidable inaccuracies, and require a considerable time investment to reformat data digitally so they are useful for analyses and mitigation planning [10]. For instance, data must be entered once on a paper form while in the field and then manually transcribed into an electronic database. After data are in an electronic database, they must then be imported into a Geographic Information System (GIS) to be visually analyzed for mitigation planning. Errors inevitably occur in the process as humans enter and transcribe WVC data manually, particularly if the handwriting on the paper form is illegible. Location data may also be prone to data entry errors. For instance, the nearest marker may not be visible from the carcass location or the road may not have any markers, which can make reporting an accurate location difficult or impossible.

Researchers have been aware of the difficulties associated with WVC data for many years, and as a result, have been actively developing new methods with the goal of improving accuracy and efficiency. As early as 2005, Ament et al. [22] developed a system in which observers used Personal Data Assistants (PDAs) to electronically record data on animal carcasses and to generate spatially accurate location coordinates using integrated Global Positioning

System (GPS) technology. This system represented a breakthrough in WVC data collection because it not only increased location accuracy, but it also standardized data collection and eliminated transcription errors. Donaldson and Lafon also used this PDA system in Virginia [23]. The use of PDAs, however, did not solve all WVC data collection problems, because PDAs still required the user to periodically transfer data from the PDA to a database for storage, which can be cumbersome when many users are reporting data across large geographic areas. Additionally in about 2006, PDAs began to be replaced by smartphones as the technology of choice. Consequently, PDA reporting systems have not been widely adopted for WVC data collection.

Another reporting system for WVCs was developed by Hesse et al. [24] in 2007. Their system used an inexpensive (~100 USD) but lesser known device called the Otto-Driving Companion. This device was attached to the dashboard of the vehicle, and it allowed the motorist to report animal carcasses with the push of a button while driving. The system generated spatially accurate locations using GPS, but was limited by the number species that could be reported. Again, WVC data had to be downloaded manually from each device to a database for the information to be useable. While this represented another step forward in WVC data collection, the Otto-Driving Companion has not been widely accepted.

Most recently, a small number of states and provinces (i.e., California, Idaho, Maine, and British Columbia) have developed web applications for reporting WVCs [25]. These web-based systems allow users to report animal carcasses by accessing a website where they enter location and species information. Some systems even allow users to upload photos of animal carcasses. The development of web applications for reporting WVC data is a significant advancement that standardizes data collection and eliminates transcription, but these systems have two important limitations: 1) users must have internet access, and 2) users must define carcass locations based on what they know about the road location. The requirement of internet access requires personal

computer users to either record the data or remember it until they have access to their computer. Web applications can be accessed with mobile devices, they require mobile broadband internet which is incomplete in most states, especially in rural areas where many WVCs occur. Web applications also require users to define the locations of WVCs manually, so there is the potential for significant location error to occur; although most web applications now have built in map viewers (e.g., Google Maps) that allow users to zoom to and select a location on the map, which makes defining the location relatively easy. However, locations errors associated with this technique are unknown and largely dependent on the user.

Presently there is no widely adopted WVC data collection system that is both efficient for users and accurate for geographic locations. My intent was to create a data collection system that increased efficiency and accuracy, but also had the potential to be broadly accepted and used. I also desired to create a system that seamlessly integrated WVC data collection, storage, and analysis. In this paper, I review the development and testing of the WVC Reporter. The WVC Reporter is a smartphone-based reporting system that combines a mobile web application for data collection, a centralized database for data storage, and a desktop web application for analyses. I found that the WVC Reporter produced accurate, nearly error free location data. Additionally, efficiency was greatly increased because data entry time was reduced and transcription was eliminated. Finally the web application improved the ease and effectiveness of WVC data analyses. The WVC Reporter represents a step forward in the continued pursuit to improve WVC data collection.

Methods

Study Area

The WVC Reporter was developed and tested in Utah (219,807 km²), which is located in the southwestern United States. The Utah landscape is topographically diverse with elevations ranging from 663-4,413 m [26]. The climate for much of the state is considered semi-arid (127-381 mm precipitation annually), but high elevation areas can receive considerably more precipitation (>1,473 mm) [27]. Three major ecoregions comprise the majority of the state: the Colorado Plateau, the Wasatch and Uinta Mountains, and the Central Basin and Range [28]. As a result, Utah is ecologically diverse and inhabited by a wide variety of plants and animals that are adapted to an array of habitats from salt desert shrub lands to alpine tundra [29].

Utah is largely a rural state with 75 % of the land area being federally or state owned [26]. There are, however, several urban areas along the front of the Wasatch Mountains in central Utah, where the majority of the state's 2.8 million residents live [30]. According to the latest census estimate, Utah was the 3rd fastest growing state [31] in the United States. Consequently, the state is rapidly becoming urbanized [32]. The growing human population has increased demand for transportation and traffic volumes have doubled in the past 30 years (1980-2010) [33]. In 2010, it was estimated that 42.8 billion km were driven on the states 73,413 km of roads [33,34].

Wildlife-vehicle collisions commonly occur in Utah and are a considerable public safety concern [35]. Most reported wildlife vehicle collisions in Utah involve mule deer (*Odocoileus hemionus*) [35], which is the state's most abundant wild large mammal [36]. Vehicle collisions with mule deer in Utah result in an average of 7.5 million (USD) in damages each year [37]. Consequently, mitigation measures such as wildlife crossings and exclusionary fencing have been used to address the problem [38].

WVC Data Collection

Surveys for wildlife carcasses using automobiles have been conducted systematically in Utah since at least 1998 [39]. Automobile surveys were done by Utah Department of Transportation (UDOT) contractors. During the study, UDOT contractors were obligated to drive ~2,800 km of roads twice a week (Monday and Thursday) throughout the year. UDOT contractor routes were selected because they had high numbers of WVCs. During surveys UDOT contractors were required to remove all animal carcasses that were detected on the road surface, the median, and the road shoulder. They also were required to keep detailed records of the species removed and their locations. Utah Division Wildlife Resources (UDWR) employees also removed and reported animal carcasses that occurred on roads other than those covered by UDOT contractors. UDWR employees did not conduct systematic surveys, but reported carcasses opportunistically. Prior to implementation of the WVC Reporter system, both agencies recorded animal carcass data using the pen/paper method.

WVC Reporter System

The WVC Reporter system consists of three integrated components: 1) a mobile web application, 2) a database, and 3) a desktop web application (Figure 5.1). The mobile web application was designed for in-field data collection. It allows the user to report information on wildlife carcasses using a smartphone. When reporting a wildlife carcass, the user simply clicks on the mobile web application bookmark and a report form opens. The report form contains a dropdown menu of wildlife species that are commonly encountered. If the species being reported is not available in the menu, it can be entered manually. The user also enters the sex (male, female, or unknown) and age class (adult, juvenile, or unknown) of the animal. Optional information that can be reported includes a carcass fat measurement (an indicator of health in ungulates) and an ID number if the animal was involved in a research study and marked.

For each reported carcass, the mobile application generates a number of pieces of information automatically. For example, the mobile web application accesses the smartphone GPS and acquires coordinates (latitude/longitude) for the location. Coordinates are then used to determine the nearest highway and marker automatically. This eliminates all data entry errors associated with location information. The mobile web application also reports the user, time, and date. When the user is finished entering information in the report form, the send button transfers data via a mobile internet connection to the WVC Reporter database. If mobile internet service is unavailable, the information is stored in the phone until the next report is submitted.

The mobile web application is compatible with most iPhone and Android smartphones. Specific device requirements include iOS Safari 3.2+, Android Browser 2.1+, or Google Chrome 10.0+. The programming code for the mobile web application was written in HTML5, CSS, and JavaScript. The HTML5 geolocation Application Program Interface (API) was used to enable location data collection, and the application cache allows the mobile web application to be used even when there is no internet connection available. Programming for all components of the WVC Reporter was done by the Utah Automated Geographic Reference Center (AGRC).

The WVC Reporter database serves as the central repository for all reports that are submitted using the mobile web application. The database is dynamic and updated when reports are submitted through an ESRI ArcGIS Server Feature Service. The database is an ESRI ArcSDE Geodatabase, and it is housed in a Structured Query Language (SQL) Server at the AGRC in Salt Lake City, Utah.

The desktop web application was designed to make it easier for planners, maintenance crews, and wildlife managers to use WVC data. To accomplish this, the web application serves as: 1) a map to view carcass locations at user defined scales, 2) a place to download current WVC data, 3) a way to enter carcass data manually, and 4) a link to the mobile web application. To map

carcass locations, the desktop web application uses ESRI's ArcGIS Server and ArcGIS API for JavaScript. The web application is dynamically linked to the WVC Reporter database, so mapped carcass locations represent the most current data available. Rather than display all carcass locations on the map regardless of the spatial extent, the map viewer shows clusters of carcass locations as circles, where the size of the circle represents the number of carcasses in the area (Figure 5.2). As one zooms in on specific locations within the state, the circles become progressively smaller and eventually disappear at fine scale extents showing only the actual carcass locations. This provides an efficient means to see where WVC hotspots occur regardless of the scale extent the map is viewed at. Carcass locations also can be overlaid on one of seven different base maps. The high-resolution aerial imagery base map provides an excellent backdrop for analyzing WVC patterns, because landscape features such as vegetation, rivers, human developments, agricultural fields, and roads are clearly visible at fine scale extents. Additionally, the terrain base map shades relief making topography appear three dimensional, which is helpful for viewing carcass location with respect to major topographic features such as drainages. To add additional context not available in the base maps, I included GIS layers for wildlife crossing locations, exclusionary fencing, marker locations, and management regions (UDOT and UDWR) that can be toggled on and off by the user. The map viewer also includes data filters (date, species, and management region) allowing the user to modify data to suit their specific needs. For fine-scale WVC analysis, users can also enter a highway number (e.g.; US 6) and section (e.g., markers 210-213), and the map viewer will zoom to that location and summarize WVC data for that area (Figure 5.2). Finally, the map viewer allows displayed data to be exported as a PDF, which provides the user with a way to share data or create figures for reports.

While the map viewer provides an efficient means to visualize WVC patterns, in some situations it may be desirable to perform more sophisticated spatial analyses. To facilitate this, the

desktop web application allows the user to download the WVC Reporter database as either an ESRI shapefile or a dbf file. The shapefile is a common GIS format that allows carcasses location to be easy imported into GIS software where spatial analyses can be performed. The download function also respects the data filters in the desktop web application.

When designing the desktop web application, I realized not all agency personnel reporting WVC collision data would have access to smartphones and consequently some information would still be collected on paper forms. To address this situation, the desktop web application has a report form for manually entering carcass locations. It essentially functions the same as the mobile web application report form, with the exception that the user has to define the carcass location manually by either entering GPS coordinates (latitude/longitude or UTM), the highway/ marker, or the street address. Once the location information is entered, the user is able to verify the location information was correct by viewing the location on a built-in map viewer.

The final function of the desktop web application is to serve as a location to link to the mobile web application. Before field technicians can use the mobile application on their individual smartphones, they must first access the web application (<https://wvc.mapserv.utah.gov/wvc/desktop/index.php>), click on the mobile app link, and then bookmark the location on their smartphone. The desktop web application was programmed using the same languages as the mobile application, and it works with nearly all commonly used web browsers (Internet Explorer 7+, Chrome, Firefox, and Safari).

Location Error

I tested the WVC reporter application using a Motorola Droid X smartphone (Model 10083V2-B-K1, Verizon, New York, New York, USA) and an Apple iPhone 4 (Model A1349, Apple, Inc., Cupertino, California, USA). To estimate the horizontal error for locations collected with these phones, I tested them at random locations on highways throughout the state of Utah. At

each random location, I recorded location coordinates using a mapping-grade Archer Differential Global Positioning System (DGPS) receiver (Model XF101, Juniper Systems, Logan, Utah, USA) that was capable of sub-meter accuracy. I used locations collected with DGPS receiver to represent the “true” location. Additionally at each random point, I recorded location coordinates using the smartphones and a recreation-grade Garmin GPS receiver (Model eTrex Legend H, Garmin International, Inc., Olathe, Kansas, USA). I included the recreation-grade GPS in testing to see how the smartphones compared to a standalone GPS receiver. All location data were imported into ArcGIS 10.1 (ESRI, Redlands, California, USA) for analysis. Location error was estimated as the Euclidean distance between the true location and the points collected by the test units. Because the location errors were not normally distributed, I reported the medians and median absolute deviations (MADs) instead of means and standard deviations. I also used the nonparametric Kruskal–Wallis test to test for differences in location errors between units. All statistical tests for this study were performed using R 2.14.1 (R Development Core Team, Vienna, Austria). To estimate how much spatial accuracy improved, I compared the location error for my smartphones to the location error (401 m) estimated by Gunson et al. [10] for reporting only the highway and marker.

Data Entry Time

I estimated the amount of time required to report carcasses using the WVC Reporter application under field conditions. For both smartphones, I recorded data entry time in seconds using a stopwatch. The reported data entry times represents the time from when the mobile web application was opened on the smartphone until all data was entered and the submit report button was pressed. Data entry times were also non-normal, so I reported medians and MADs. I tested for differences in data entry times between smartphones using the Wilcoxon rank-sum test. I did not measure data entry times for the pen/paper method but assumed it took 60-90 seconds to

report each carcass using this technique. I also made the same assumption for the amount of time it takes to transcribe written data into an electronic database.

Data Entry Errors

I estimated reporting errors for the previous system of paper forms and transcription. I could only estimate reporting errors for location data. Location data were reported as both the highway/marker, and as GPS coordinates (easting, northing) reported in UTM's. For each record, I verified the GPS coordinates matched with the reported highway/marker. When GPS coordinates were associated with a highway, but the reported highway/marker did not match the location, I assumed that the highway/marker was reported incorrectly. When GPS coordinates did not coincide with a highway, I assumed that the coordinates were reported incorrectly.

Costs Savings

To estimate the total cost savings from using the WVC Reporter, I used the data entry time saved for both infield data collection and transcription and assumed the mean hourly wage for those reporting and transcribing data was \$12/hr. All dollar amounts in this paper represent United States currency (USD).

Results

WVC Reporter System

I began development on the WVC Reporter in July of 2011. The system was thoroughly tested for a 6 month period (October 2011- March 2012) prior to its release. Development costs for programming and testing totaled \$34,000. Annual maintenance costs were estimated to be \$1,500. The WVC Reporter officially went into use across Utah on April 16, 2012. Use of the WVC Reporter application was restricted to UDWR and UDOT personnel, UDOT contractors,

and select wildlife and transportation professionals. During the first year of use, 6,822 carcasses were reported by 47 different users across the state. A total of 43 different species were reported, but the majority of carcasses (85 %) were mule deer (Figure 5.3). Additionally, spatial patterns were clearly apparent at multiple scale extents when using the map viewer to assess carcass locations. For instance at the statewide scale, the majority of WVCs occurred in the north central portion of the state (Figure 5.2). At the scale of individual highways, carcasses appeared to be clustered in hotspots along highways. At fine scale extents, the landscape and infrastructure features associated with hotspot locations were clearly visible when viewed in conjunction with a high-resolution aerial imagery (Figure 5.2).

Location Error

Location error varied between the units I tested ($K = 25.26, p < 0.01$). The Droid X had the highest median location error (5.2 m). The location error for the iPhone 4 was lower (4.6 m), but similar to the Droid X. The Garmin GPS had the lowest median location error (2.4 m). The use of smartphones decreased location error 99 % over reporting highway/marker locations. Using a Garmin GPS instead of the smartphones I tested would have further decreased location error < 1 % (Table 5.1).

Data Entry Time

Data entry time varied between the Droid X and the iPhone 4 ($W = 3528, p = < 0.01$). The median data entry time for the Droid X (22.0 s) was shorter than median data entry time for the iPhone 4 (26.5 s). Using smartphones over the pen/paper method decreased data entry time 56-76 %, which I estimated saved approximately 63.5-128.9 person hours of work over a one year period. Additionally, data transcription was eliminated, which resulted in a time savings of 113.7-170.5 person hours of work annually.

Data Entry Errors

I measured data entry error rates for carcasses that were reported using the pen/paper method and then transcribed into an electronic database (Table 5.2). Data entry error rates were highest for marker locations (19 %), intermediate for GPS coordinates (10 %), and lowest for highway names (1 %). The overall data entry error rate for all location data was 10 %.

Cost Savings

I estimated \$2,126-\$3,593 was saved in data entry and transcription time during one year in Utah.

Discussion

In 2008, Bissonette and Cramer [11] recommended accurate and standardized WVC data as a priority for transportation planning and wildlife management in North America. Given the recent advances that have taken place in mobile communications and electronics, it seemed promising that WVC data collection could be improved by incorporating these modern advances. The WVC Reporter was specifically designed to leverage modern technologies to produce accurate and standardized WVC data. The system accomplished this by integrating several modern advances (smartphones, GPS, a mobile application, mobile broadband internet, an electronic database, a web application, a map viewer) into a seamless method for collecting, managing, and using data. The system was developed and tested at a statewide scale to serve as a proof of concept, but has the potential to be adopted throughout North America because it produced accurate data, improved efficiency, and enhanced data management and use.

Accuracy was increased by reducing errors associated with location data and by reducing data entry errors. On average, location error for the smartphones I tested was only ~4-5 m and the largest recorded error for either phone was 23 m. However, location error for highway/marker

method can be > 800 m, even if locations are reported correctly [10]. Location error of that magnitude can potentially obscure relationships with vegetation, topography, and infrastructure that can be highly variable within an 800 m area. Alternatively, locations collected with smartphones were accurate enough that relationships with landscape features and infrastructure were readily apparent, providing managers with a clearer understanding of the nature of the problem. Furthermore, using a standalone GPS unit did not substantially decrease location error over using smartphones.

With WVC data that is both spatially accurate and temporally current, management can be conducted at a fine scale to address problems as they arise. For instance, deer are occasionally killed on roads that have exclusionary fencing. This can happen when fencing becomes damaged or gates are left open. If maintenance crews observe that deer carcasses are being reported in area with exclusionary fencing over a short time period of days or weeks, they can examine the location for damaged fencing or open gates, allowing them to quickly address the problem while it is occurring to prevent further WVCs at that location. When WVC data are collected on paper forms, data can be months to years old before they are processed and examined. Subsequently the opportunity to prevent WVCs is reduced. This is just one example of how management can be enhanced with accurate WVC data.

The WVC Reporter also improved data accuracy by reducing errors that occurred from data collection and transcription. When using the pen/method for data collection, ~10% WVC locations had associated errors. Errors occurred in highway names, marker locations, and GPS coordinates. The highest error rate occurred for marker locations (19 %), which was likely due to the fact that markers are not always visible from carcass locations. GPS coordinates, which consist of a long string of numbers (e.g., 12 T 505698 4405622), were also prone to errors (10 %) when collected and transcribed manually. Errors in GPS coordinates are especially problematic,

because a seemingly innocuous error in which one digit is off by one number can make a location unusable. The errors that occur from manually recording and transcribing data were virtually eliminated using the WVC Reporter because location data were recorded by the mobile application using the smartphone's GPS capabilities, rather than by the user manually.

There was also a marked increase in efficiency when I compared the WVC Reporter system to the pen/paper method as data collection time was reduced 55-75 % and transcription was eliminated. For one year of reporting in Utah, the time savings from these two factors alone equates to 4-7 weeks of work for one person. Time savings could be considerably more for states with higher numbers of WVCs. In one year Pennsylvania had an estimated ~115,571 deer-vehicle collisions [40]. If I assumed that these data were recorded with the WVC Reporter rather than on paper forms, it is possible that 1.4-2.4 person-years of work could be saved. Today state agencies are consistently asked to do more with fewer resources. They may not have the time or person power to process data that requires considerable labor to make it useable for management purposes. The use of WVC Reporter allowed managers to focus on analysis and planning rather than data entry and preparation.

Time savings produced by increased efficiency inevitably translates into reduced costs for agencies. I estimated that in one year thousands of dollars (\$2,126-\$3,593) were saved in data entry and transcription time in Utah. There are additional savings that occur in data management and analysis. A total of 47 state employees and contractors reported WVC data throughout Utah. Collecting data entry forms from all of those individuals at regular intervals is not trivial; it requires a considerable commitment of time and effort, which is not required with the WVC Reporter system. Additionally data analysis is streamlined with WVC Reporter, because data do not have to be prepared for GIS analysis, and analysis time is reduced because data can be instantly viewed by simply accessing the desktop web application. These cost savings are more

difficult to estimate, but are possibly equivalent to or exceed those costs saved on data entry and transcription.

The WVC Reporter had its own associated expenses. System development and testing was moderate (\$34,000). Additionally, annual maintenance costs (\$1,500) were 4.4% of the development costs. The WVC Reporter system also requires investment in smartphones and wireless data plans. These costs can be partially defrayed by the fact that many people already have smartphones, which would necessitate them only downloading the mobile application at no cost. When WVC Reporter costs are viewed in context of the problem, the investment in the system appears relatively minor. The average economic cost of a deer-vehicle collision has been estimated to be \$8,388 and as high as \$30,773 for a moose-vehicle collision [8]. Consequently only ~4 deer-vehicle collisions or ~1 moose-vehicle collision would need to be prevented to pay for system development. Additionally, if one human fatality could be prevented (estimated value of a human life is \$ 3.3-9.1 million [8,41,42]), the system would pay for itself many times over.

While the WVC Reporter has advanced data collection and use, the capabilities of the system could be expanded further. As most smartphones now have built in cameras, the mobile web application could easily be modified to allow users to submit photos of carcasses. Additionally survey effort of users could be quantified by programming the mobile web application to track user's movements while they are conducting carcass surveys. Quantifying survey effort allows for more rigorous analysis of WVC data. The WVC Reporter system could also be linked to a warning system for drivers. The warning system could be designed as a mobile application that notified drivers whenever they entered an area that was currently experiencing high numbers of WVCs. The alert produced by the warning system could also notify drivers if they are traveling during a time of day when WVCs are more likely to occur (e.g., evening or early morning). This form of warning system would provide drivers with the best

information available on WVC conditions. Given the effectiveness of the WVC reporter in collecting location data, the system could easily be modified for recording sightings of live wildlife, collecting data on wildlife crossing infrastructure, or it could be used for general maintenance issues like reporting potholes and broken/missing road signs. The applications for this type of technology are broad and could potentially result in significant benefits for agencies, wildlife, and the public.

In just the past 5 years, citizen science has emerged as a powerful tool to address scientific problems that were previously too costly, difficult, or labor intensive for researchers to undertake [43]. Citizen science involves recruiting the general public to collect data for scientific research, and it has the power to focus the efforts of many individuals on large scale problems. WVCs are truly a large scale problem that affects much of the developed world [5,17,44]. The scope of the problem is beyond what can be addressed by agencies and researchers alone. For instance in Utah, < 4 % of the roads were surveyed for carcasses by contractors. Given the ease of data collection and management with the WVC Reporter system, it could easily be extended to a citizen science enterprise where the general public reported WVCs on roads that were not surveyed by agencies. Citizen science programs for WVC data collection have successfully been implemented in California (California Roadkill Observation System), Maine (Wildlife Road Watch), and Idaho (Roadkill and Wildlife Salvage) using web applications. Despite the challenges associated with citizen science programs (i.e., inexperienced observers, double reporting, people management), the expansion of WVC data collection to large scales will likely depend on the degree to which the general public can be leveraged using modern electronic reporting systems such as these.

References

1. Al-Ghamdi AS, AlGadhi SA (2004) Warning signs as countermeasures to camel–vehicle collisions in Saudi Arabia. *Accident Analysis & Prevention* 36: 749–760.
2. Ramp D, Wilson VK, Croft DB (2006) Assessing the impacts of roads in peri-urban reserves: road-based fatalities and road usage by wildlife in the Royal National Park, New South Wales, Australia. *Biological Conservation* 129: 348–359.
3. Mkanda FX, Chansa W (2011) Changes in temporal and spatial pattern of road kills along the Lusaka-Mongu (M9) highway, Kafue National Park, Zambia. *South African Journal of Wildlife Research* 41: 68–78.
4. Noro M (2010) Analysis of deer ecology and landscape features as factors contributing to deer-vehicle collisions in Hokkaido, Japan. Washington: Transportation Research Board.
5. Bruinderink GWTA, Hazebroek E (1996) Ungulate traffic collisions in Europe. *Conservation Biology* 10: 1059–1067.
6. Forman RTT, Alexander LE (1998) Roads and their major ecological effects. *Annual Review of Ecology and Systematics* 29: 207–231.
7. Bissonette JA, Kassar CA, Cook JC (2008) Assessment of costs associated with deer-vehicle collisions: human death and injury, vehicle damage, and deer loss. *Human-Wildlife Conflicts* 2: 17–27.
8. Huijser MP, McGowen PT, Fuller J, Hardy A, Kociolek A (2008) Wildlife-vehicle collision reduction study: report to Congress. Bozeman: Western Transportation Institute.
9. Langley RL, Higgins SA, Herrin KB (2006) Risk factors associated with fatal animal-vehicle collisions in the United States, 1995–2004. *Wilderness & Environmental Medicine* 17: 229–239.

10. Gunson KE, Clevenger AP, Ford AT, Bissonette JA, Hardy A (2009) A comparison of data sets varying in spatial accuracy used to predict the occurrence of wildlife-vehicle collisions. *Environmental Management* 44: 268–277.
11. Bissonette JA, Cramer PC (2008) Evaluation of the use and effectiveness of wildlife crossings. Washington: National Cooperative Highway Research Program, Transportation Research Board, National Research Council. Report 615. Available: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_615.pdf, Accessed.
12. Huijser MP, Wagner ME, Hardy A, Clevenger AP, Fuller JA (2007) Animal-vehicle collision data collection throughout the United States and Canada. Washington: Transportation Research Board.
13. Ford AT, Clevenger AP, Bennett A (2009) Comparison of methods of monitoring wildlife crossing-structures on highways. *Journal of Wildlife Management* 73: 1213–1222.
14. Clevenger AP, Chruszcz B, Gunson KE (2001) Highway mitigation fencing reduces wildlife-vehicle collisions. *Wildlife Society Bulletin* 29: 646–653.
15. Clevenger AP, Waltho N (2000) Factors influencing the effectiveness of wildlife underpasses in Banff, Alberta, Canada. *Conservation Biology* 14: 47–56.
16. Seiler A (2004) Trends and spatial patterns in ungulate-vehicle collisions in Sweden. *Wildlife Biology* 10: 301–313.
17. Grift EA van der, Pouwels R (2006) Restoring habitat connectivity across transport corridors: identifying high-priority locations for de-fragmentation with the use of an expert-based model. In: Davenport PJ, Davenport JL, editors. *The Ecology of Transportation: Managing Mobility for the Environment*. Environmental Pollution. Netherlands: Springer. pp. 205–231.

18. Gagnon JW, Dodd NL, Ogren KS, Schweinsburg RE (2011) Factors associated with use of wildlife underpasses and importance of long-term monitoring. *Journal of Wildlife Management* 75: 1477–1487.
19. Huijser MP, Duffield JW, Clevenger AP, Ament RJ, McGowen PT (2009) Cost–benefit analyses of mitigation measures aimed at reducing collisions with large ungulates in the United States and Canada: a decision support tool. *Ecology and Society* 14: 15.
20. Trombulak SC, Frissell CA (2000) Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14: 18–30.
21. Stoner D (1925) The toll of the automobile. *Science* 61: 56–57.
22. Ament R, Galarus D, Richardson H, Hardy A (2007) Roadkill observation collection system (ROCS). Bozeman: Western Transportation Institute.
23. Donaldson B, Lafon N (2010) Personal digital assistants to collect data on animal carcass removal from roadways. *Transportation Research Record: Journal of the Transportation Research Board* 2147: 18–24.
24. Hesse G, Rea RV, Klassen N, Emmons S, Dickson D (2010) Evaluating the potential of the Otto® Wildlife GPS device to record roadside moose and deer locations for use in wildlife vehicle collision mitigation planning. *Wildlife Biology in Practice* 6: 1–13.
25. Lee T, Quinn MS, Duke, D. (2006) Citizen, science, highways, and wildlife: Using as web-based GIS to engage citizens in collecting wildlife information. *Ecology and Society* 11: 11.
26. Leydsman McGinty EI (2009) Land ownership of Utah. In: Banner RE, Baldwin BD, Leydsman McGinty EI, editors. *Rangelands Resources of Utah*. Logan: Utah State University Cooperative Extension Service. pp. 9–23.

27. Gillies RR, Ramsey RD (2009) Climate of Utah. In: Banner RE, Baldwin BD, Leydsman McGinty EI, editors. Rangelands Resources of Utah. Logan: Utah State University Cooperative Extension Service. pp. 39–45.
28. Griffith GE, Omernik JM (2009) Ecoregions of Utah (EPA). In: Cleveland CJ, editor. Encyclopedia of Earth. Washington: Environmental Information Coalition. Available: [http://www.eoearth.org/article/Ecoregions_of_Utah_\(EPA\)](http://www.eoearth.org/article/Ecoregions_of_Utah_(EPA)). Accessed 11 May 2013.
29. Welsh SL, Atwood AN, Higgins LC, editors (1993) A Utah Flora. Provo: Brigham Young University. 986 p.
30. Economic Research Service (2013) State Fact Sheets: Utah. United States Department of Agriculture. Available: <http://www.ers.usda.gov/data-products/state-fact-sheets/state-data.aspx?StateFIPS=49&StateName=Utah#.UdsyAUHCZ8F>. Accessed 8 July 2013.
31. U. S. Census Bureau (2010) Resident population data. Available: <http://www.census.gov/2010census/data/>. Accessed 25 April 2013.
32. Leydsman McGinty EI (2009) Urbanization in Utah. In: Banner RE, Baldwin BD, Leydsman McGinty EI, editors. Rangelands Resources of Utah. Logan: Utah State University Cooperative Extension Service. pp. 153–156.
33. UDOT (2010) Vehicle miles of travel. Utah Department of Transportation. Available: <http://www.udot.utah.gov/>. Accessed 25 April 2013.
34. Pope C, McEwan A (2012) 2012 UDOT annual statistical summary. Salt Lake City: Utah Department of Transportation..
35. West PW (2008) UDOT wildlife and domestic animal accident toolkit. Salt Lake City: Utah Department of Transportation.
36. Bernales HH, Hersey KR, Aoude A (2011) Utah big game annual report 2011. Salt Lake City: Utah Division of Wildlife Resources.

37. Bissonette JA, Kassar CA, Cook JC (2008) Assessment of costs associated with deer-vehicle collisions: human death and injury, vehicle damage, and deer loss. *Human Wildlife Conflicts* 2: 17–27.
38. Cramer PC (2012) Determining wildlife use of wildlife crossing structures under different scenarios. Logan: Utah State University. Report UT-12 .07. Available: <http://trid.trb.org/view.aspx?id=1147953>. Accessed 8 July 2013.
39. Bissonette JA, Rosa S (2012) An evaluation of a mitigation strategy for deer-vehicle collisions. *Wildlife Biology* 18: 414–423.
40. State Farm (2012) Deer collisions increase, WV #1 again, Arkansas #9 nationally. State Farm Insurance Company. Available: http://www.statefarm.com/aboutus/_pressreleases/2012/deer-crash-rankings-ar. Accessed 29 April 2013.
41. Lefler N, Fiedler R, McGee H, Pollack R, Miller J (2011) Market analysis of collecting fundamental roadway data elements to support the highway improvement program. Washington: United States Department of Transportation, Federal Highway Administration.
42. Sinha P, Braun F (2010) Regulatory impact analysis (RIA) for existing stationary compression ignition engines NESHAP. Research Triangle Park, North Carolina: United States Environmental Protection Agency.
43. Gura T (2013) Citizen science: amateur experts. *Nature* 496: 259–261.
44. Conover MR, Pitt WC, Kessler KK, DuBow TJ, Sanborn WA (1995) Review of human injuries, illnesses, and economic losses caused by wildlife in the United States. *Wildlife Society Bulletin* 23: 407–414.

Table 5.1. The estimated location error and entry time for data collected with smartphones and a standalone GPS at 60 random locations throughout Utah.

Unit	Location Error (m)				Data Entry Time (s)			
	n	Median	MAD	Range	n	Median	MAD	Range
Droid	60	5.2	4.5	0.7-23.2	111	22.0	5.9	10.0-42.0
iPhone	60	4.6	2.9	0.2-21.0	122	26.5	9.6	15.0-87.0
Garmin	60	2.4	1.3	0.3-8.0	NA	NA	NA	NA

Table 5.2. Data entry errors for location data that was collected using the pen/method and then transcribed into an electronic spreadsheet.

Location Data	n	Errors	% Error
Highway	1836	23	1.3
Mile Marker	1836	356	19.4
Easting Coordinate	1836	196	10.7
Northing Coordinate	1836	189	10.3
Total	7344	764	10.4

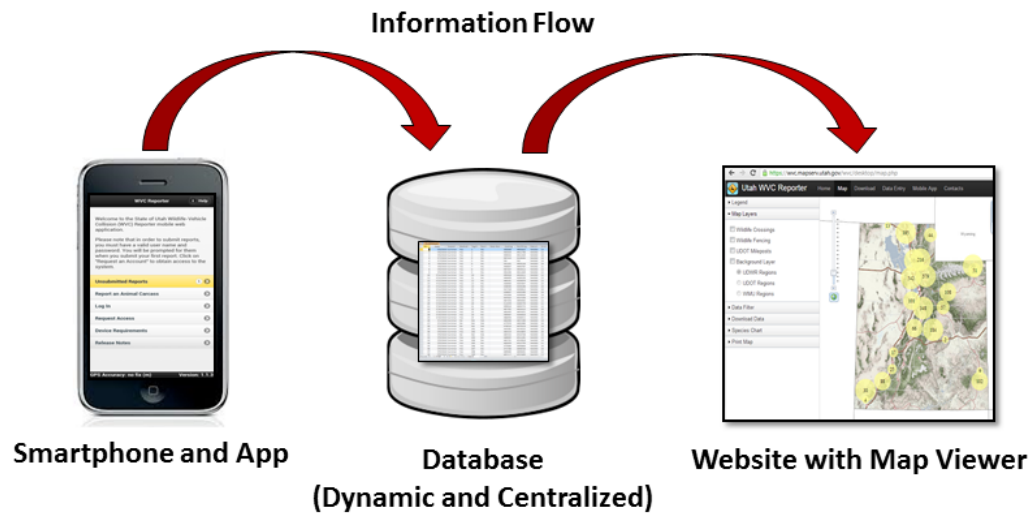


Figure 5.1. Flow of information through the WVC Reporter system.

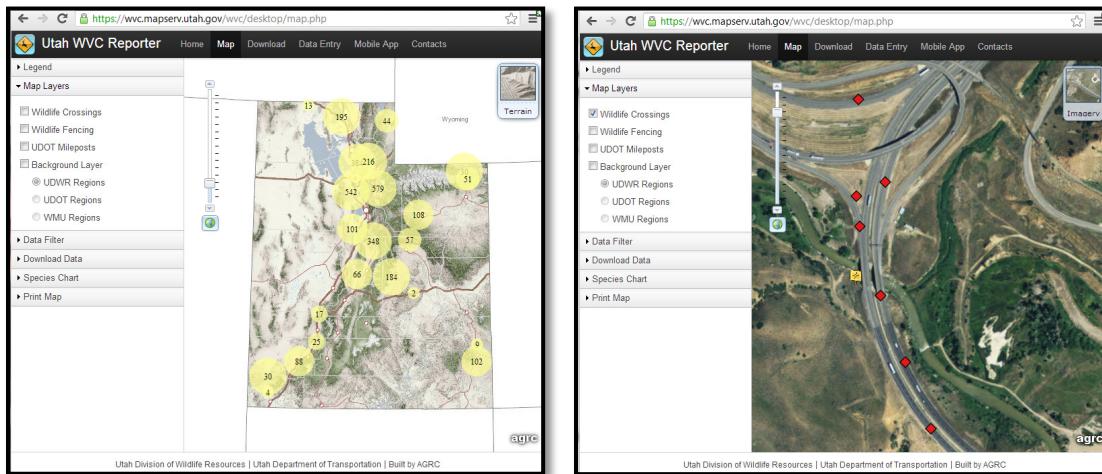


Figure 5.2. WVC Reporter map viewer depicting spatial patterns in wildlife-vehicle collisions.

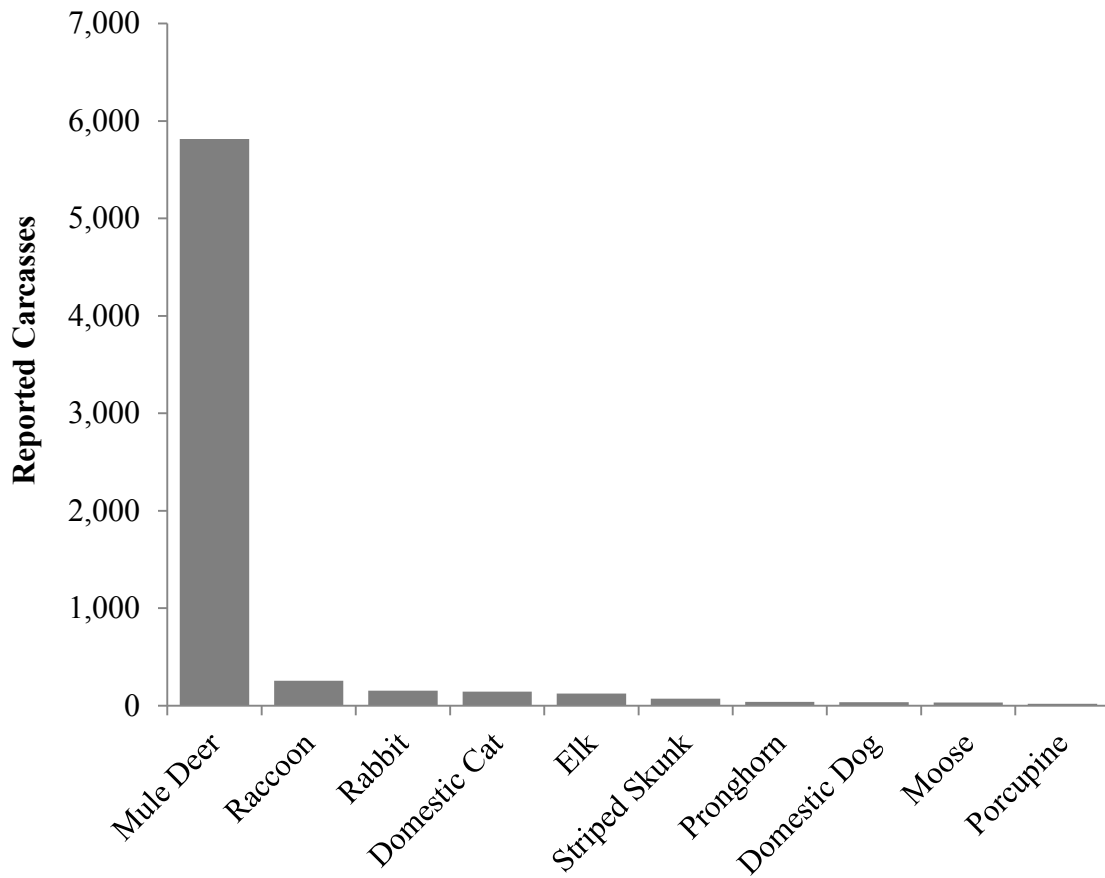


Figure 5.3. Animal carcasses reported using the WVC Reporter system in Utah.

CHAPTER 6

CONCLUSIONS

Roads are an essential part of modern communities and economies (Forman et al. 2003, Larsson et al. 2010). As the human population grows, traffic volumes are expected to continue to rise, and roads will be built and expanded to accommodate the increasing demand for transportation (FHWA 2010). As a result, the effect that roads and vehicle traffic have on wildlife will likely intensify, making it imperative that managers understand how roads are affecting wildlife so mitigation can be directed accordingly.

In Utah, considerable amounts of mule deer (*Odocoileus hemionus*) habitat are now bisected by roads with increasing traffic volumes (UDOT 2012). Mule deer are commonly involved in vehicle collisions (West 2008), and there is concern that roads may be impacting populations. The focus of my research was to: 1) estimate the number of vehicle collisions involving deer in Utah, 2) examine the demographic effects of vehicle collisions, 3) determine how movements and survival were impacted by roads, and 4) create an electronic, smartphone-based system for reporting vehicle collisions.

Accurate estimates of DVCs are needed to effectively mitigate the effects of roads and to properly manage deer populations (Bissonette and Cramer 2008). However, there is great uncertainty associated with most DVC estimates because commonly used DVC data sources are inherently biased and the bias is rarely accounted for in estimates (Huijser et al. 2007). In chapter 2, I estimated the number of DVCs in Utah using carcass surveys conducted with automobiles and all-terrain vehicles. I found that uncorrected carcass surveys underestimated the actual number of DVCs substantially and detected only 41 % of deer killed in vehicle collisions along roads administered by the Utah Department of Transportation. After correcting for this bias, I

estimated that vehicle collisions were removing 2-5 % of the mule deer population in Utah annually, which was less than what was being harvested by hunters (7-9 %).

The effect that DVCs have on deer populations depends not only on the number of deer killed but also on the demographic groups removed, because deer demographic groups have distinct fecundity and survival rates (Gaillard et al. 2000). In deer populations, prime-aged females (2-7 yrs) are the most important demographic group to population growth (Gaillard et al. 1998). In chapter 3, I observed that 65 % of deer killed in vehicle collisions were female and 40 % were adult females. Of adult females, 98 % were prime-aged, which indicates that vehicle-related mortality could potentially exert a strong influence on deer abundance. Additionally, when I compared vehicle collision rates among deer species in Utah, I found that mule deer were 7.4-8.7 times more likely to be involved in vehicle collisions than elk and 1.2-2 times more likely than moose. Although mule deer appeared to be more vulnerable to vehicle collisions than other species and a high percentage of prime-age females were being killed, mule deer abundance has been relatively stable for the past 20 years, while traffic volumes have steadily increased. Given this evidence, it is likely that current vehicle collision levels are not yet high enough to cause population declines at the statewide scale extent.

The rate at which DVCs occur is spatially and temporally variable (Biggs et al. 2004, Kassir and Bissonette 2005). Understanding the sources of this variation is the key to effective mitigation that will enhance driver safety and reduce deer mortality. In chapter 4, I examined how natural variation in climate during winter influenced deer distribution, movement patterns, and DVC rates. I found that precipitation and snow depth differed considerably between winters, with precipitation decreasing 50 % and snow depth decreasing 48 % during the second winter. In response, the spatial distribution of deer changed, with deer occurring at higher elevations and 55 % farther from roads. As result, crossing rates decreased as much as 96 % on roads with high

traffic volumes during the second winter. Reduced crossing rates were likely responsible for much of the 75 % decrease in deer-vehicle collisions during the second winter. My data suggest a causal mechanism by which winter conditions affect DVC rates, which can help managers predict when DVC rates are likely to rise, allowing them to warn drivers of the increased danger.

There currently is a need for management agencies to be able to efficiently collect accurate and standardized wildlife-vehicle collision (WVC) data (Huijser et al. 2007), because it is the foundation of mitigation projects that benefit both drivers and wildlife (Ford et al. 2009). Prior to this study, there was no widely adopted electronic reporting system that was both efficient and accurate. In chapter 5, I discussed the development and testing of a smartphone-based system for reporting WVC data. The WVC Reporter system consisted of a mobile web application for data collection, a database for centralized storage of data, and a desktop application for viewing data. The smartphones that I tested for use with the application produced accurate spatial locations (median error = 4.6-5.2 m), and reduced location error considerably (99 %). Using the application also increased efficiency by reducing data entry times 56-76 % and eliminating data transcription. Additionally, data collected WVC reporter system had ~10 % fewer data entry errors. The desktop web application was an effective tool for accessing data and visualizing wildlife-vehicle collision patterns. The WVC Reporter integrated several modern technologies into a seamless method for collecting, managing, and using WVC data. The development costs (\$35,000) for the system were minor when viewed in context of the potential benefits of having spatially accurate and temporally current wildlife-vehicle collision data. The WVC Reporter represents a step forward in WVC data collection and use, and the system has the potential to be widely adopted, because it addresses many of the problems associated with earlier electronic reporting systems.

LITERATURE CITED

- Biggs, J., S. Sherwood, S. Michalak, L. Hansen, and C. Bare. 2004. Animal-related vehicle accidents at the Los Alamos National Laboratory, New Mexico. *The Southwestern Naturalist* 49:384–394.
- Bissonette, J. A., and P. C. Cramer. 2008. Evaluation of the use and effectiveness of wildlife crossings. National Cooperative Highway Research Program, Transportation Research Board, National Research Council. Report 615, Washington, D.C., USA.
<http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_615.pdf>. Accessed 8 Jul 2013.
- FHWA. 2010. Key freight transportation challenges. Federal Highway Administration.
<<http://www.ops.fhwa.dot.gov/freight/publications/>>. Accessed 9 Sept 2013.
- Ford, A. T., A. P. Clevenger, and A. Bennett. 2009. Comparison of methods of monitoring wildlife crossing-structures on highways. *Journal of Wildlife Management* 73:1213–1222.
- Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. *Road ecology: science and solutions*. Island Press, Washington, D.C., USA.
- Gaillard, J.-M., M. Festa-Bianchet, and N. G. Yoccoz. 1998. Population dynamics of large herbivores: variable recruitment with constant adult survival. *Trends in Ecology & Evolution* 13:58–63.
- Gaillard, J.-M., M. Festa-Bianchet, N. G. Yoccoz, A. Loison, and C. Toigo. 2000. Temporal variation in fitness components and population dynamics of large herbivores. *Annual Review of Ecology and Systematics* 31:367–393.

- Huijser, M. P., M. E. Wagner, A. Hardy, A. P. Clevenger, and J. A. Fuller. 2007. Animal-vehicle collision data collection throughout the United States and Canada. Transportation Research Board, Washington, D.C., USA.
- Kassar, C. A., and J. A. Bissonette. 2005. Deer-vehicle crash hotspots in Utah: data for effective mitigation. Utah State University, Logan, Utah, USA.
- Larsson, P., S. W. A. Dekker, and C. Tingvall. 2010. The need for a systems theory approach to road safety. *Safety Science* 48:1167–1174.
- UDOT. 2012. Traffic on Utah's highways. Utah Department of Transportation. <<http://www.udot.utah.gov/>>. Accessed 1 Jul 2013.
- West, P. W. 2008. UDOT wildlife and domestic animal accident toolkit. Utah Department of Transportation, Salt Lake City, Utah, USA.

APPENDIX

10-21-2013

Scott Davis
Utah Automated Geographic Reference Center
1 State Office Building Rm 5130
Salt Lake City, Utah 84114

Daniel Olson
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5230 Old Main Hill
Logan, Utah 84322

To whom it may concern:

This letter is to inform you that I give Daniel Olson full permission to use my name on coauthored papers in fulfillment of dissertation requirements at Utah State University.

A handwritten signature in black ink, appearing to read 'Scott Davis', with a long horizontal flourish extending to the right.

Scott Davis



GARY R. HERBERT
Governor
GREGORY S. BELL
Lieutenant Governor

State of Utah

DEPARTMENT OF NATURAL RESOURCES

MICHAEL R. STYLER
Executive Director

Division of Wildlife Resources

GREGORY SHEHAN
Division Director

October 21, 2013

Daniel Olson
Utah State University
5230 Old Main Hill
Logan, Utah 84322

To whom it may concern:

This letter is to inform you that I give Daniel Olson full permission to use my name on coauthored papers in fulfillment of dissertation requirements at Utah State University.

Sincerely,

A handwritten signature in cursive script that reads "Ashley D. Green".

Mr. Ashley D. Green
Chief, Habitat Section

ADG

10/21/2013

Pat Jackson
Utah State University
5230 Old Main Hill
Logan, Utah 84322

Daniel Olson
Utah State University
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Logan, Utah 84322

To whom it may concern:

This letter is to inform you that I give Daniel Olson full permission to use my name on coauthored papers in fulfillment of dissertation requirements at Utah State University.

Pat Jackson

CURRICULUM VITAE

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EDUCATION

- 2013 PhD Wildlife Biology, Utah State University, GPA: 3.88
 PhD Dissertation: Assessing Vehicle-Related Mortality of Mule Deer in Utah
- 2008 MS Wildlife and Wildlands Conservation, Brigham Young University. GPA: 3.98
 MS Thesis: Ecology of California Bighorn Sheep in Utah
- 2006 BS Wildlife and Wildlands Conservation, Brigham Young University. GPA: 3.98
- 2003 AS Business Management, Brigham Young University Idaho. GPA: 3.52

RESEARCH EXPERIENCE

- Aug. 2008– Dec 2013 **Graduate Research Assistant (40+ hrs/wk) Utah State University**
 I conducted a statewide research project to assess the effects of roads on mule deer in Utah. I helped design the study, write the grant proposal, and implement the project. During the project, I directly managed 5 field technicians. I estimated detection of deer carcasses and the number of deer being killed in vehicle collisions. I monitored the survival and movements of 32 GPS marked deer. Additionally, I helped create a smartphone application for reporting wildlife carcasses on roads. I used GIS extensively to model movements and habitat use of deer. I developed a GIS tool to detect movement barriers for wildlife. I expect to publish 4 peer-reviewed publications as the result of this research.
- Dec. 2005- Dec. 2008 **Graduate Research Assistant (40+ hrs/wk) Brigham Young University**
 I helped capture, reintroduce, and monitor bighorn sheep on the Stansbury Mountains in Utah. I collared and collected measurements on >140 bighorn sheep. I programmed and deployed GPS tracking collars on bighorn rams. I also collected information on habitat use, survival, demographics, and reproduction. Additionally, I developed an accurate GIS logistic regression model to predict habitat use of reintroduced bighorn sheep.

- Sept. 2005- Dec. 2005 **Research Assistant (20 hrs/wk) Brigham Young University**
I assisted a graduate student in monitoring chukar partridge in the Great Basin of Utah. I worked alone on remote desert mountain ranges tracking the movements, water use, and survival of radio collared chukars.
- Dec. 2003- Sept. 2005 **Research Assistant (20-40 hrs/wk) Brigham Young University**
I assisted a graduate student in augmenting a declining population of sage grouse in Strawberry Valley, Utah. I captured and collared >200 sage grouse. I monitored 50-80 radio collared birds weekly. I documented cause-specific mortality, habitat use, and flocking behavior. This required the use of snowmobiles, ATVs, and boats.
- May 2003- Aug. 2003 **Biological Technician (40 hrs/wk) United States Forest Service**
May 2001- Aug. 2001 I assisted a fisheries biologist in stream monitoring and fish spawning habitat evaluation. I visited all major streams in the forest and quantified vegetation, erosion, water quality, sedimentation, and channel type. I also surveyed streams for salmon redds, and was trained in electro-fishing.

TEACHING EXPERIENCE

- Fall 2011 **Ecology of Animal Populations 6400**
I was a co-instructor for this class and was responsible for teaching 10, 3-4 hour labs. The class focused on estimating demographic parameters of wild animals and constructing models with these estimates to examine population dynamics. I taught students how use program Mark, Distance, and R. I graded all lab reports and helped students design analyses for their own datasets.
- Fall 2009 **Geographic Information Systems 5540**
I taught 12 labs on GIS that allowed students to build proficiency in geoprocessing data and solving spatial problems. Lab topics included data acquisition, georeferencing, vector and raster analyses, DEM construction, morphometric analysis, modeling, and others. I graded all lab reports and helped students design analyses for their own datasets.
- Winter 2008 **Wildlife Behavioral Ecology 554**
I taught 3 lectures on group cooperation, foraging, and anti-predator behavior. I helped students design behavioral studies and analyze results. I graded all quizzes and tests.

- Fall 2007 **Ecology of Large Mammals in North America 695**
I lead 10 discussions on the management and ecology of large mammals and specific topics included: modeling population dynamics, nutritional ecology, genetic applications.
- Fall 2007 **Principles of Wildlife Ecology 225**
I taught 12 lectures on topics that included: the history of wildlife management, animal behavior, and population modeling. I also advised students on scientific writing techniques, graded research papers, and attended to all teaching responsibilities.
- Winter 2007 **Techniques for Wildlife Investigations and Management 357**
I designed and taught laboratories on GPS, GIS, population estimation, and vegetation sampling. I also taught several lectures in addition to grading assignments and tests.
- Fall 2006 **Wildlife and Wildlands Conservation 115**
I assisted a professor in counseling students on natural resource career planning. I directed the class when the professor was absent, and I was responsible for all grading.

PUBLICATIONS

- 2013 Shannon, J. M., J. C. Whiting, R. T. Larsen, **D. D. Olson**, J. T. Flinders, T. S. Smith, and R. T. Bowyer. Population response of reintroduced bighorn sheep after observed commingling with domestic sheep. *Journal of Wildlife Diseases* (in review)
- 2012 Whiting, J. C., **D. D. Olson**, J. M. Shannon, R. T. Bowyer, R. W. Klaver, and J. T. Flinders. Timing and synchrony of births in bighorn sheep: implications for reintroduction and conservation. *Wildlife Research* 39: 565-572.
- 2008 **Olson, D. D.**, J. M. Shannon, J. C. Whiting, and J. T. Flinders. History, status, and population structure of California bighorn in Utah. *Biennial Symposium Northern Wild sheep and Goat Council* 16:161-177
- 2008 Shannon, J. M., **D. D. Olson**, J. C. Whiting, and J. T. Flinders. Current status of Rocky Mountain bighorn in Utah. *Biennial Symposium Northern Wild sheep and Goat Council* 16:178-195

- 2008 **Olson, D. D.**, J. M. Shannon, J. C. Whiting, S. L. Petersen, R. T. Larsen and J. T. Flinders. A robust approach for modeling bighorn sheep habitat. ESRI User Conference Proceedings.
- 2008 Shannon, J. M., **D. D. Olson**, J. W. Whiting, J. T. Flinders. Can GIS models predict habitat use of reintroduced bighorn sheep? ESRI User Conference Proceedings.

POPULAR ARTICLES AND NEWSLETTERS

- 2012 Green, A., P. C. Cramer, **D. D. Olson**, M. S. Schwender. From roadkill to roadwise: Utah's effort to reduce mule deer mortality along highways. Mule Deer Foundation Magazine. January/February 2012.
- 2009 **Olson, D. D.** Stansbury Mountains Bighorn Population. Utah Foundation for North American Wild sheep Magazine. February 2009.
- 2007 **Olson, D. D.**, J. M. Shannon, and J. C. Whiting. Counting and estimating survival of bighorn lambs. Conservation Connection. Winter 2007, issue 16.

GRANTS AND OTHER FUNDING

2009-2013	Utah Division of Wildlife Resources	\$302,000
2011-2012	Utah Department of Transportation	\$35,000
2005-2008	Utah Division of Wildlife Resources	\$164,000

PRESENTATIONS

- 2013 **Olson, D. D.** and J. A. Bissonette. Roads and mule deer: a look at what is happening in Utah. Utah Chapter of the Wildlife Society Annual Meeting, Bryce Canyon, Utah.
- 2013 **Olson, D. D.**, J. A. Bissonette, and C. Garrard. Detecting movement barriers for wildlife. Utah Chapter of the Wildlife Society Annual Meeting, Bryce Canyon, Utah.

- 2013 **Olson, D. D.** and J. A. Bissonette. Tracking wildlife-vehicle collisions with smartphone technology. Idaho Chapter of the Wildlife Society Annual Meeting, Coeur d'Alene, Idaho.
- 2013 **Olson, D. D.** and J. A. Bissonette. Assessing the effects of vehicle-related mortality in mule deer. Mule Deer Working Group Winter Meeting, Salt Lake City, Utah.
- 2012 **Olson, D. D.** and J. A. Bissonette. The Utah wildlife-vehicle collision reporter. Utah Department of Transportation Annual Conference, Salt Lake City, Utah.
- 2012 **Olson, D. D.** and J. A. Bissonette. Habitat fragmentation: When do roads become barriers to deer movements? The Wildlife Society Annual Conference, Portland, Oregon.
- 2012 **Olson, D. D.**, C. Garrard, and J. A. Bissonette. Movement Barrier Tool. ESRI User Conference App Fair, San Diego, California.
- 2012 **Olson, D. D.** and J. A. Bissonette. Using smartphones to track wildlife-vehicle collisions in the information age. ESRI User Conference, San Diego, California.
- 2012 **Olson, D. D.** and J. A. Bissonette. Impact of roads on mule deer in Utah. Western Association of Fish and Wildlife Agencies Summer Meeting, Waikoloa, Hawaii.
- 2012 **Olson, D. D.** and J. A. Bissonette. Impact of roads on mule deer in Utah. Utah Division of Wildlife Resources Annual Habitat Meeting, Midway, Utah.
- 2012 **Olson, D. D.** and J. A. Bissonette. Tracking wildlife-vehicle collisions in Utah with smartphone technology. Utah Chapter of the Wildlife Society Annual Meeting, Springdale, Utah.
- 2012 **Olson, D. D.** and J. A. Bissonette. Assessing the impacts of roads on mule deer in Utah. Utah Chapter of the Wildlife Society Annual Meeting, Springdale, Utah.
- 2011 **Olson, D. D.**, J. A. Bissonette, M. C. Schwender, P. C. Cramer. A smartphone application for reporting wildlife vehicle collisions. The Wildlife Society Annual Conference, Waikoloa, Hawaii.
- 2009 **Olson, D. D.** Does DEM resolution effect vector ruggedness measure results? ESRI User Conference, San Diego, California.

- 2009 **Olson, D. D.**, J. M. Shannon, J. C. Whiting, S. L. Petersen, R. D. Larsen, and J. T. Flinders. How well do GIS-based models predict habitat use for bighorn sheep? Utah Chapter of the Wildlife Society Annual Meeting, Bryce Canyon, Utah
- 2009 Shannon, J. M., **D. D. Olson**, J. C. Whiting, J. T. Flinders, T. S. Smith. Survival rates of bighorn sheep before and after exposure to exposure to domestic sheep? Utah Chapter of the Wildlife Society Annual Meeting, Bryce Canyon, Utah
- 2009 Shields, A. V., **D. D. Olson**, J. M. Shannon, J. C. Whiting, and J. T. Flinders. The Stansbury Mountains bighorn population: after three years, how is it doing? Utah Chapter of the Wildlife Society Annual Meeting, Bryce Canyon, Utah
- 2009 Sproat, K. K., J. M. Shannon, **D. D. Olson**, J. C. Whiting, T. S. Smith, and J. T. Flinders. Differences in habitat use of reintroduced bighorn sheep along the Wasatch Front, Utah. Utah Chapter of the Wildlife Society Annual Meeting, Bryce Canyon, Utah
- 2009 Takasaki, S. Y., J. M. Shannon, S. B. Bates, J. C. Whiting, **D. D. Olson**, and J. T. Flinders. Comparing coyote diets to prey densities on Antelope Island State Park? Utah Chapter of the Wildlife Society Annual Meeting, Bryce Canyon, Utah
- 2008 **Olson, D. D.**, S. Petersen, J. T. Flinders. Predicting habitat use of translocated bighorns. ESRI User Conference, San Diego, California.
- 2008 Shannon, J. M., **D. D. Olson**, J. W. Whiting, J. T. Flinders. Testing a predictive habitat model for lambing habitat of reintroduced bighorn. ESRI User Conference. San Diego, California.
- 2008 **Olson, D. D.**, J. S. Shannon, J. C. Whiting, J. T. Flinders. The status and history of California bighorn sheep in Utah. Northern Wild sheep and Goat Council. Midway, Utah.
- 2008 Shannon, J. M., **D. D. Olson**, J. W. Whiting, J. T. Flinders. Current status of Rocky Mountain bighorn in Utah. Northern Wild sheep and Goat Council. Midway, Utah.

- 2008 **Olson, D. D.**, J. C. Whiting, and J. T. Flinders. Update on the Stansbury Mountains reintroduction. The Foundation for North American Wild Sheep. Salt Lake City, Utah.
- 2008 **Olson, D. D.** and J. T. Flinders. Bighorn sheep research and becoming a wildlife biologist. Wildlife and Range Club. Brigham Young University, Provo, Utah
- 2008 **Olson, D. D.** and J. T. Flinders. Movements and associations of translocated male bighorn sheep (*Ovis canadensis*). Utah Chapter of the Wildlife Society Annual Meeting, Springdale, Utah
- 2007 **Olson, D. D.**, J. C. Whiting, and J. T. Flinders. An ecological assessment of bighorn sheep on the Stansbury Mountains. Brigham Young University. Provo, Utah.
- 2006 **Olson, D. D.**, J. C. Whiting, and J. T. Flinders. Reintroduction of Bighorn Sheep on the Stansbury Mountains. The Foundation for North American Wild Sheep. Salt Lake City, Utah.
- 2006 **Olson, D. D.**, J. C. Whiting, and J. T. Flinders. Stansbury bighorn sheep translocation. Utah Chapter of the Wildlife Society Annual Meeting. Moab, Utah.
- 2006 **Olson, D. D.**, J. C. Whiting, and J. T. Flinders. Mortality and habitat use of bighorn sheep on the Stansbury Mountains. Utah Division of Wildlife Resources, Springville, Utah.

PROFESSIONAL SERVICE

2012-Present Invited reviewer for PLOS (Public Library of Science) One