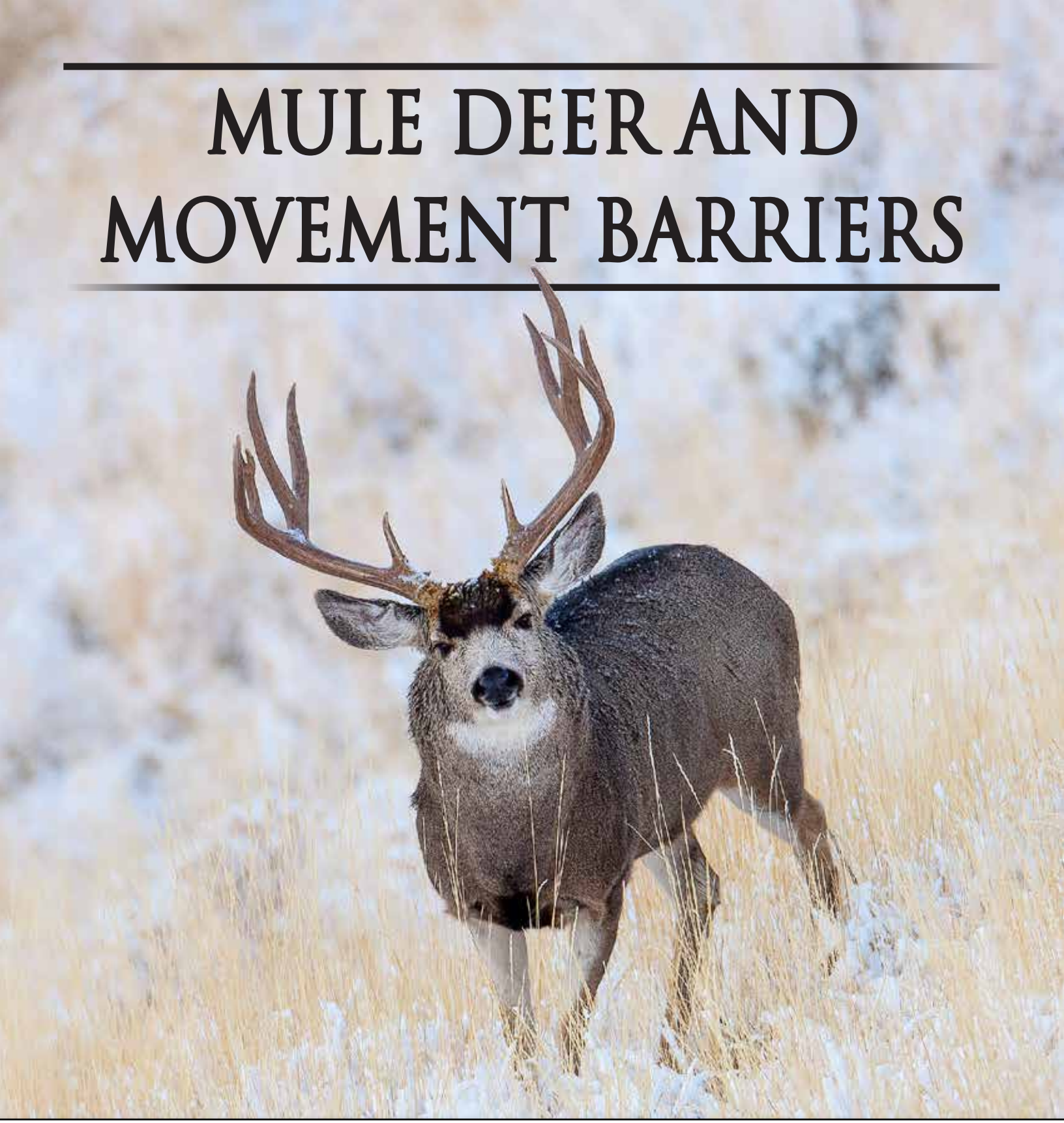
MULE DEER AND MOVEMENT BARRIERS



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WAFWA
Western Association of Fish & Wildlife Agencies

Mule Deer Working Group

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PREFACE

Mule deer populations are faced with daunting challenges due to the advent of rapidly growing human populations and their necessary infrastructure: roads, canals, railways, highways, and associated fences. We developed this document to provide wildlife managers with a sense of these challenges and the state of knowledge about how they can be addressed. Long-term habitat alteration was among several challenges identified in Mule Deer Conservation: Issues and Management Strategies (deVos et al. 2003). Movement barriers are only a small subset of all habitat alterations, and this topic received relatively little attention in the literature until recently. Over the last decade, somebody opened the floodgates and now movement barrier mitigation is among the most rapidly developing fields in wildlife management. Researchers and managers have compiled abundant literature in diverse locations. Due to the volumes that have been written, the value of producing this document specifically for mule deer managers was debated. This brief compilation alone references >150 other relevant pieces of literature on movement barriers, and some of those references exceed 300 pages in length. A document of this nature can only introduce the topic, raise awareness, promote dialogue, and uncover knowledge gaps that require further investigation.

Nevertheless, several important considerations for mitigating barriers to movement can be identified and implemented to ensure that managers, engineers, and planners can incorporate the appropriate engineering features that mule deer and other wildlife need to maintain connectivity, genetic interchange, and herd health. These important considerations can reduce the risk of human injury and death while limiting financial losses. Although economists have found ways to place dollar values on the life of a mule deer and a human being, reducing or eliminating that loss is truly priceless.

This document should help managers identify the type of data that assists in determining how movement corridors may be identified. This document should also assist the manager in determining when to engage with planners and encourage planners to engage with wildlife biologists. And finally, this document should provide some proven techniques for mitigating movement barriers, while providing a resource to locate many more.

ACKNOWLEDGEMENTS

While there are many reviewers and contributors that have made this a better product, Jody Wilkinson with the Nevada Department of Wildlife, Game Division, deserves special recognition. During the transition of this document from a manuscript housed on an Arizona Game and Fish Department computer to its new home with the Nevada Department of Wildlife, there was a catastrophic hard drive failure. No electronic word processing copy of the document could be located. Jody willingly retyped the manuscript, correcting many of the grammatical errors in the process.

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Photo courtesty of Wyoming Game and Fish Department

INTRODUCTION

Mule deer (*Odocoileus hemionus*) are broadly distributed throughout western North America, occurring from Mexico to the coastal islands of Alaska (Wallmo 1981). Throughout their range, mule deer are a popular species and have substantial economic importance. A survey of wildlife-related recreation conducted by the United States Fish and Wildlife Service indicated that 2.9 million people hunted big game in the 19 western states and they spent $8.7 billion on hunting-related expenses (USFWS 2013). The survey also reported that deer (*Odocoileus* spp.) were the most popular big game species for hunters to pursue. In addition to being an important game species, mule deer are charismatic and have inherent esthetic value for wildlife enthusiasts (Kie and Czech 2000). For example, 27.1 million people in the western USA watched deer and other wildlife and spent $21.1 billion on the activity (USFWS 2013).

Major changes are occurring throughout much of mule deer range. The latest census indicated that the human population in the western United States grew 16% from 2000 to 2010, which was 60% higher than the national average. The 5 states with the highest growth rates in the last decade (Nevada 35%, Arizona 25%, Utah 24%, Idaho 21%, and Texas 21%) were within the distribution of mule deer (US Census Bureau 2010). This growth is placing increasing challenges on mule deer populations.

With population growth and increased natural resource demands comes habitat fragmentation, which negatively affects some wildlife populations (Lindenmayer and Fischer 2006). Habitat fragmentation can occur when any barrier bisects otherwise continuous habitat, creating semipermeable or impermeable barriers to wildlife movements, including those of mule deer (Noss and Cooperrider 1994, Sawyer et al. 2013). Barriers causing habitat fragmentation can include fences, canals, housing developments, wind, solar, gas, and oil energy developments, transmission lines, mines, railways, and roads. Barriers to wildlife movement reduce or eliminate the ability of individuals to disperse, migrate, forage, and find mates (Baur and Baur 1990, Noss and Cooperrider 1994, Ball and Dahlgren 2002, Rondinini and Doncaster 2002). The disruption of these processes can decrease individual fitness, recruitment, and ultimately population abundance. Barriers can create discontinuous, isolated subpopulations, which makes genetic exchange more challenging (Keller and Largiadèr 2003, Epps et al. 2005, Roedenbeck and Voser 2008).

Fences are among the more common movement barriers and became prominent in the western United States primarily for control of livestock distribution. When built improperly, fences can substantially hinder mule deer movement and cause mortality (Howard 1991, Harrington and Conover 2006). Harrington and Conover (2006) documented higher mortality rates attributable to fence entanglement for deer than for elk (*Cervus elaphus*) or pronghorn (*Antilocapra americana*) and further noted that juveniles were 8 times more likely to die due to fences than adults. Combination fences that include woven-wire sections on the bottom with a strand of barbed or smooth wire on top were the highest source of mortality (Harrington and Conover 2006). To improve permeability for juvenile and adult deer, the bottom of livestock fencing should be at least 16 inches from the ground and the top of the fence should be a maximum of 40 inches; additionally for strand-wire fences, the spacing between the top 2 wires should be at least 12 inches to reduce the probability of entangling legs of deer that try to jump the fence (Paige 2012). Limited research has been conducted on the effects of pole fences (wood or metal) that seem to have favorable permeability for wildlife, yet high costs preclude their use except in the smallest areas (e.g., surrounding water sources).

Photo courtesty of Tim Torell

Conversely, fencing can be used as an intentional barrier to wildlife to exclude them from targeted areas, such as agricultural crops, roads, and airports (VerCauteren et al. 2006). Fences greater than 7 feet in height substantially reduce the ability of deer to jump over and provide a nearly impermeable barrier (VerCauteren et al. 2010). Exclusionary fences alone provide an impermeable barrier to wildlife but when coupled with wildlife crossings can provide an effective means to reduce deer-vehicle collisions (DVC) on roadways while maintaining habitat connectivity (Gagnon et al. 2011a, Sawyer et al. 2012, Cramer 2013).

In many mule deer habitats, canals (or aqueducts) can also hinder mule deer movement and cause mortality when individuals become entrapped within the canal (Rautenstrauch and Krausman 1989). Mortalities can be reduced by placing escape features within the canal (Rautenstrauch and Krausman 1989) or using exclusionary fencing to prevent mule deer from entering the canal. In addition to exclusionary fencing, strategically placing crossing structures over canals will increase permeability

of the barrier (Tull and Krausman 2001, Popowski and Krausman 2002).

Urban, suburban, or rural housing developments can fragment mule deer habitat, forcing mule deer to seek alternative paths or inhibit passage altogether. Mule deer tend to avoid areas immediately around large developments (Smith et al. 1989). Adopting planning and zoning guidelines that recognize appropriate corridors and designated open space will help mitigate the loss of habitat and maintain connectivity between important mule deer ranges adjacent to development (Noss and Cooperrider 1994). Conversely, increasing availability of food or water when either is scarce in the surrounding habitats may create attractants for mule deer that may draw mule deer into close association with human habitation. Under these situations, mule deer may become a nuisance within urban settings by becoming aggressive with humans, damaging ornamental vegetation, and increasing collisions with vehicles. Like white-tailed deer (*O. virginianus*) in urban areas across their range, mule deer are adapting to living in suburbia and taking advantage of anthropogenic resources like maintained landscaping and gardens.

Oil and gas extraction has occurred for decades and is known to influence mule deer distribution (Sawyer et al. 2006) and migration (Lendrum et al. 2013, Sawyer et al. 2013). Continued exploration and extraction and the associated road construction is affecting mule deer populations negatively (Sawyer et al. 2006, 2009). Recent developments in extraction methods such as hydraulic fracturing (also known as fracking) and other large-scale projects used to harness energy sources (e.g., wind, solar) have become widespread and their effects on mule deer are unclear. The effects of some actions have been identified and can be mitigated with proper planning. For example, effects of well pads and roads associated with these efforts can be estimated (Sawyer et al. 2009, Lendrum et al. 2012) and methods to reduce their effects have been identified (e.g., Lutz et al. 2011, Northrup and Wittemyer 2012).

With recent rebounds in precious metal prices, open pit mining has also increased. The mine footprint itself can create barriers to long-range movements or remove habitat that may be a resource during those movements (Merrill

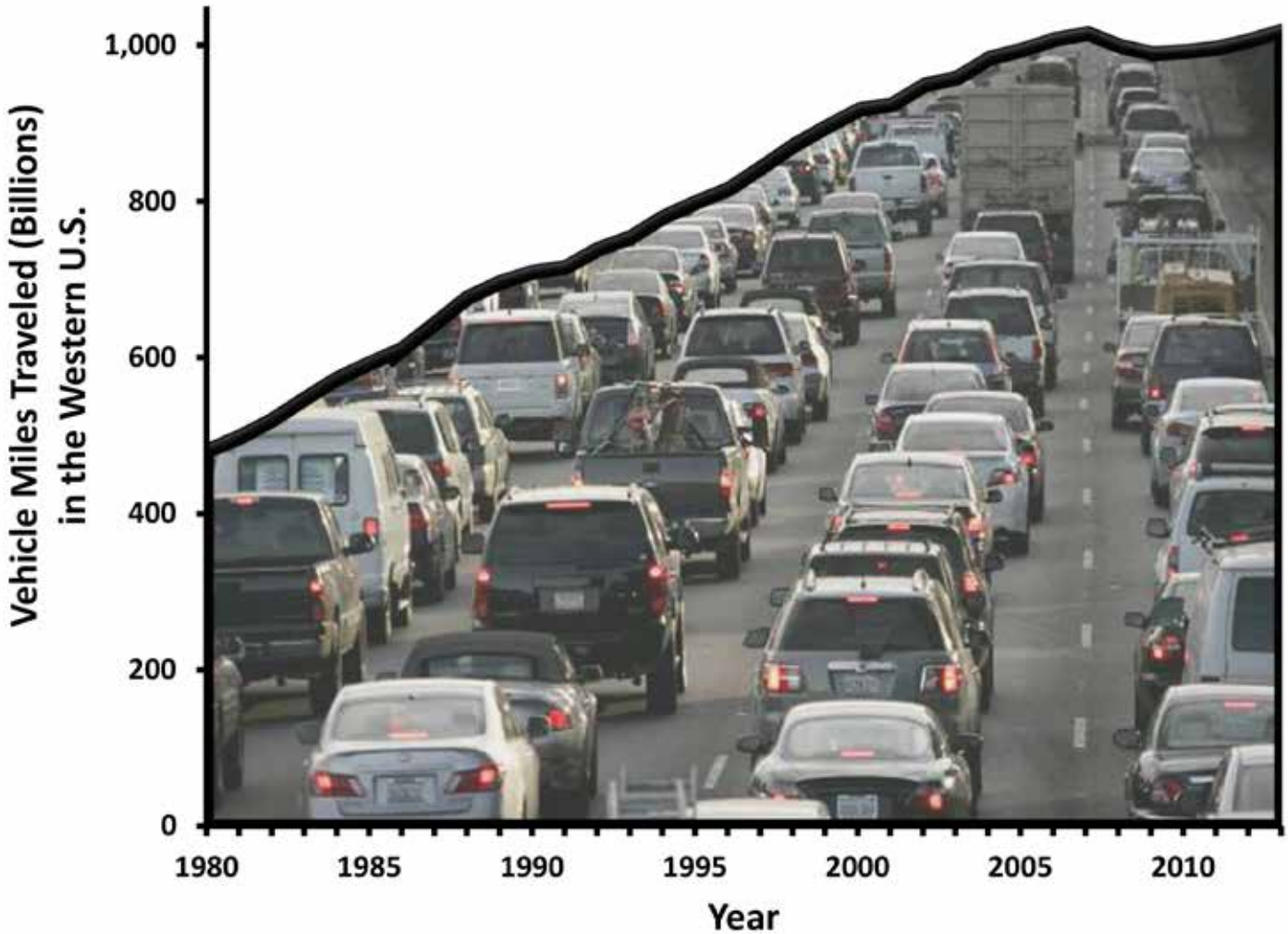

Figure 1. Vehicle miles traveled annually in the Western United States (1980–2013) as estimated by the United States Department of Transportation.

et al. 1994, Lutz et al. 2003, Blum et al. 2015). Working with mine operators to find options to mitigate effects from fragmentation and other mining activities may be the best approach (Merrill et al. 1994, Heffelfinger et al. 2006).

Railways are another known source of mortality for mule deer, yet little attention has been given to deer-train collisions. Concerns with railways are generally focused on larger species, such as moose (*Alces alces*), or species with special legal designations, such as grizzly bear (*Ursus arctos*; Andreassen et al. 2005, Pissot 2007). In most cases, mule deer mortalities along railways are caused by deer escaping deep snow or attracted by preferred food, such as grain spilled from rail cars (Gilbert et al. 1970, Wells et al.1999). Wells et al. (1999) documented that mule deer accounted for 22% of ungulates killed along the Canadian Pacific Railway, following elk (*Cervus elaphus*) (35%) and moose (30%). Mule deer mortality is substantial in some areas and plans to reduce those mortalities are warranted (e.g., Idaho Department of Fish and Game 2010). Further research on the barrier effect of railways on mule deer is needed.

Roads are a fundamental component of modern societies that facilitate the movement of people and goods, encourage economic development, and enrich social interactions (Forman et al. 2003, Larsson et al. 2010). Each day, more than 272 million miles are driven on the 1.6 million miles of roads in the western United States (FHWA 2011). Although the road network is expanded each year to accommodate the rapidly growing human population, the construction of new roads is outpaced by increases in road capacity (Forman et al. 2003). For example, traffic volumes in the West have risen 3% annually since 1980 (Figure 1, page 4), resulting in 13.3 billion more miles of vehicle traffic each year (FHWA 2011). Of all barriers to mule deer movements, roads are the most prominent and influential, given their number, distribution, and associated direct and indirect effects (Forman et al. 2003). About 62% of the western road network is within mule deer habitat (Figure 2, page 7).

While the growth and expansion of roads provide a benefit for people, they are detrimental to deer and other wildlife (Putman 1997, Forman and Alexander 1998, Trombulak and Frissell 2000, Taylor and Goldingay 2010). Deer are directly affected by roads because they are commonly involved in vehicle collisions, and most deer (>90%) die as a result of injuries sustained (Allen and McCullough 1976). Some deer populations have been substantially affected by vehicle-related mortality. In Florida, 50–74% of known mortality for the endangered Key deer (*o.v. clavium*) was due to vehicle collisions (Lopez et al. 2003). Vehicle collisions were also the leading cause of death (34% of mortality) for female mule deer in 1 study in northern Utah, and low survival rates were reported for this population (Peterson and Messmer 2011). Additionally, mule deer may be more susceptible to vehicle collisions than elk and moose (Olson et al. 2014b). The number of collisions with mule deer can be relatively higher in areas where highways transect migratory paths, winter concentrations, or essential resources, as deer are forced to cross roads under these conditions to survive (Romin and Bissonette 1996b, Sawyer et al. 2013).

In Colorado, 1.8% of mule deer does marked with telemetry devices were killed in vehicle collisions (Colorado Parks and Wildlife, unpublished data), and vehicle-related mortality accounted for 5–12% of doe mortalities from all causes. In addition, 1.7% of fawns marked with telemetry devices were killed by vehicles and comprised 4–11% of total fawn mortalities in the 5 herds (Colorado Parks and Wildlife, unpublished data). While the percentages may seem relatively small, these vehicle-related mortalities result in about 40,000 annual collisions within a deer population of about 400,000 animals.

Deer-vehicle collisions also generate considerable public interest because they are relatively common and directly affect human safety (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 (Huijser et al. 2008). According to estimates based on insurance claims from June 2012 to July 2013 (State Farm 2013), there were 197,179 vehicle collision involving deer, elk, and moose in the western United States (Figure 3). Texas had the highest number of DVCs (46,537) in the western region, but among states with primarily mule deer, DVCs/year ranged from 1,613–23,699. The number of collisions with white-tailed deer is substantially higher in the eastern United States, likely due to high traffic volume, road density and white-tailed deer abundance. In Pennsylvania alone, there are an estimated 114,933 DVCs annually.

Economic costs associated with DVCs can be substantial and include vehicle repair, medical treatment of injured drivers and passengers, loss of human life, loss of the animal involved, carcass removal and disposal, vehicle towing, and costs associated with accident investigation (Huijser et al. 2008). The reported repair costs associated with collisions involving deer has averaged $2,317 per accident (range = $1,471–3,414) over the past 30 years (Table 1). Injuries to drivers and passengers occur in about 5% of DVCs (Bissonette et al. 2008), and associated costs average $1,495 (range = $18–2,949). Human fatalities related to DVCs are relatively infrequent, but the number in the United States has risen to about 200 annually (Langley et al. 2006). For the purpose of economic analysis, each human life has been valued at $3.3–9.1 million (Huijser et al. 2008, Sinha and Braun 2010, Lefler et al. 2011). Deer mortality represents an economic loss (Bissonette et al. 2008); the mean value assigned to an individual deer is $1,232, although these estimates are variable as well (Table 2). Estimates from insurance claims indicate that there are nearly 200,000 annual DVCs in the West with a minimum estimated cost of $1.8 billion annually.

While insurance claims represent some of the best data available to evaluate DVC effects at large scales, they generally underrepresent the problem because claims are generally filed only if there is substantive vehicle damage, the motorist has comprehensive insurance coverage, and

the motorist is willing to report the accident. The degree to which insurance claims underestimate the problem is largely unknown.

Accident report data is another common method that has been used to estimate DVCs. Accident reports are collected by public safety officers that respond to vehicle accidents. Estimates of DVCs based on accident report data are routinely biased low because public safety officers generally only respond to accidents when >$1,000 in damages result (Joyce and Mahoney 2001) or if human injury or death occurs (Bissonette et al. 2008). Even when an accident meets those criteria, accidents still may not be reported by the motorist involved. Like insurance claims, the degree to which accident report data underestimates DVCs is generally unknown, but when compared to insurance claim or road-kill data, accident reports seem to be substantially lower (Knapp et al. 2007, Donaldson and Lafon 2010, Lao et al. 2012, Bissonette and Olson 2013).

Problem mule deer collision areas along roads can be identified through various methods. The most prevalent of these methods is road-kill monitoring. Road-kill monitoring identifies potential problem areas, but data must be collected accurately or some problem areas may be overlooked (Gunson et al. 2009). Existing telemetry data on movements and crossings are extremely valuable. If this data does not exist, there may be time to implement a study and incorporate during the early planning phases of new road construction. Highway developers often value telemetry data more than road-kill data. Telemetry data can assist with identifying movement corridors and detecting potential problem areas before they occur (Gagnon et al. 2009). When actual data is not available, habitat modeling based on expert opinion can identify corridors and help prioritize areas for future mitigation measures (Clevenger et al. 2002, Beier et al. 2009). Coe et al. (2015) found that high DVC areas were highly correlated with mule deer migration corridors in south-central Oregon and could help identify corridors where telemetry studies were lacking. Local wildlife experts can inform all these processes and should be involved from the start of any mitigation process. A combination of available methods can provide the best available information to address problem areas to improve mule deer movement and reduce mortalities (see Coe et al. 2015).

Direct mortality from vehicle collisions is only part of the effect on mule deer populations. Roads can affect populations through direct habitat loss. The amount of habitat lost to roads may appear trivial, but it is estimated that 1% of the land area of the United States (37,940 mi^2) is covered by roads (Forman 2000). In the West an estimated 7,300 mi^2 are covered by roads. Since 62% of those roads occur within mule deer habitat (Figure 2), habitat loss for mule deer due to roads may approach 4,600 mi^2, an area slightly smaller than Connecticut (5,544 mi^2).

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 multiple causes and may have substantial 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 changes in vegetation (Forman and Alexander 1998, Rheindt 2003, Longcore and Rich 2004). Roads may also facilitate the spread of exotic and invasive species (e.g., cheatgrass [*Bromus tectorum*]) that can alter the composition of forage species and ecological processes (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 mule deer to avoid areas adjacent to roads, especially during winter when energy conservation is important (Trombulak and Frissell 2000, Anderson et al. 2012). 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.

When roads degrade habitat, deer tend to avoid these areas. Degradation of habitat, though, is not always a consistent process. A review of the available literature (Table 2) indicates substantial variation on how mule deer respond to roads and road effects. Several studies have reported that mule deer avoid habitats near roads, but an equal number of studies have reported that they were actually selecting habitats near roads. The reasons for this varied response are unclear. Forage conditions may be improved along roadsides due to increased precipitation collection. Roads can reduce other types of disturbance (e.g., predation, human recreation) making roadsides seem safer for mule deer. Other more dominant cervids that are sympatric with mule deer, such as elk, may displace deer to areas near roads (Johnson et al. 2000, Ager et al. 2001). Some studies identify roads as a potential source of avoidance, primarily due to disturbance. Little information exists on permeability of roads to mule deer (Gagnon et al. 2007a). The ability of mule deer to successfully cross roads is dependent upon traffic volume; roads with higher traffic volumes will pose a greater barrier than roads with lower traffic volumes (Gagnon et al. 2007b, Dodd and Gagnon 2011, Coe et al. 2015). Preferred resources and essential migration may cause individual mule deer populations to tolerate higher traffic volumes when crossing roads, yet suffer greater mortality due to more frequent collisions or disturbance (Gagnon et al. 2007a, Lendrum et al. 2012).

Habitat fragmentation caused by roads hinders mule deer movements (Sawyer et al. 2013). Highway mitigation projects that include wildlife crossings are considered effective when these crossings reduce wildlife-vehicle collision rates and restore wildlife movement between fragmented habitats (Ford et al. 2008, Fortin and Agrawal 2005, Van Wieren and Worm 2001). States like Nevada and Wyoming have been maintaining movement corridors by incorporating overpasses and underpasses into roadway

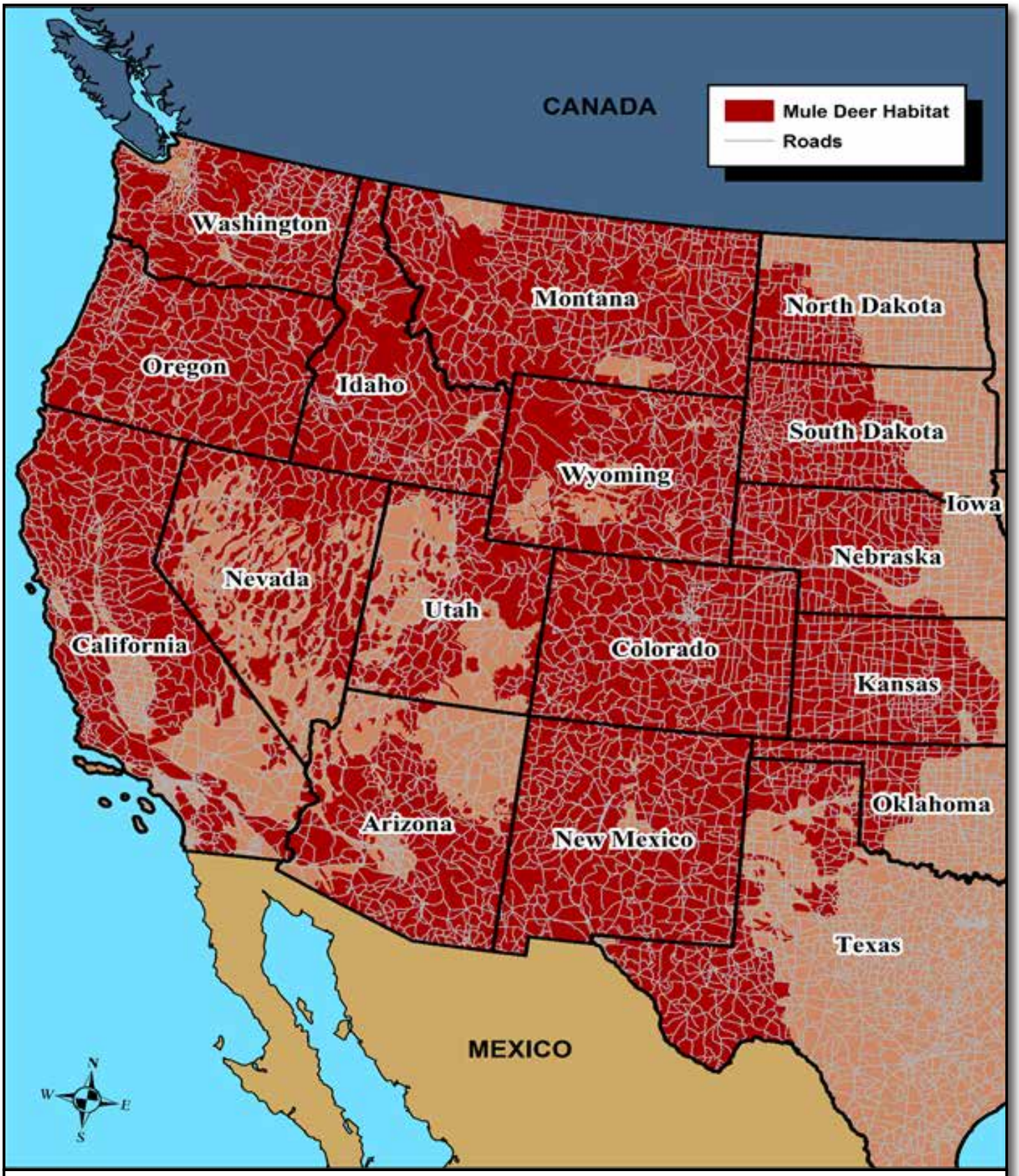

Figure 2. Mule deer habitat and the road network in the Western United States.

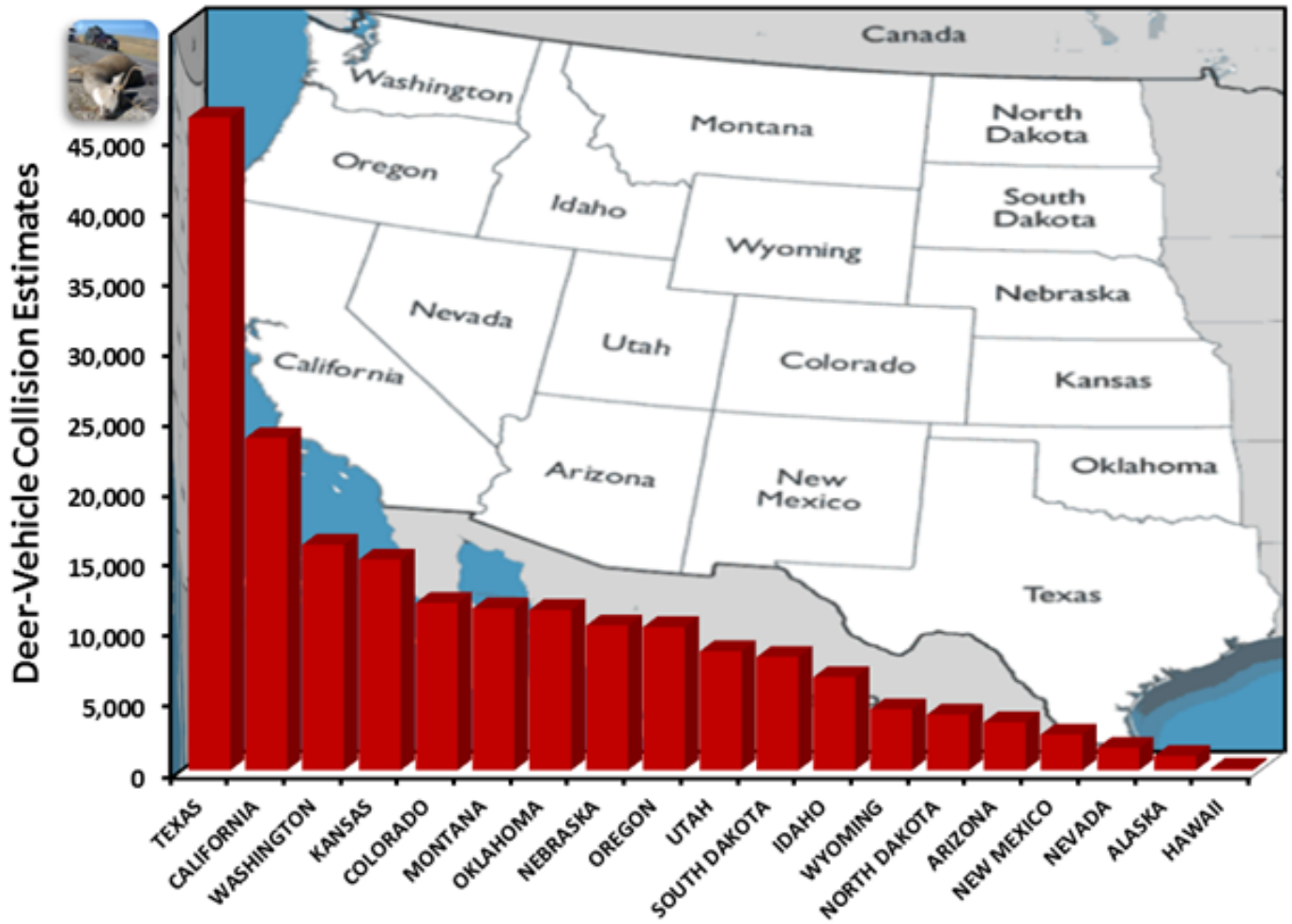

Figure 3. The number of deer-vehicle collisions in the Western United States (July 2012–June 2013) as estimated from insurance claims by State Farm Insurance (State Farm 2013). Deer-vehicle collisions estimates refer to collisions that involve deer (*Odocoileus* spp.), elk (*Cervus elaphus*), and moose (*Alces alces*).

improvements. For example, wildlife crossings have been located throughout Nevada, including several to benefit bighorn sheep (*Ovis canadensis*), mule deer, elk, feral horses, and desert tortoise (*Gopherus agassizii*). Several more crossings are currently in the planning phases throughout the West.

Crossing structures can benefit mule deer at highways. Simpson et al. (2012) documented how wildlife used overpasses and underpasses by monitoring 5 crossing structures (2 overpasses and 3 underpasses) on US Highway 93 north of Wells in northeastern Nevada. Mule deer used the crossings extensively, especially during migratory periods. After construction, >16,000 mule deer used 1 of the structures in the first 2 years alone (Simpson et al. 2012), and the number of successful crossings has continued to increase with each seasonal migration and now exceed 35,000 (N. Simpson, Nevada Department of Transportation, personal communication). This crossing kept mule deer off the roadway and out of the way of motorists during migrations, substantially reducing collision risk and increasing motorist safety. Mule deer used the overpasses more frequently (82%) and exhibited less hesitation when compared to underpasses (Simpson et al. 2012). In contrast, a study in Wyoming (6 underpasses and 2 overpasses) documented the number of migratory mule deer that crossed US Highway 191 and found 80% (~32,000) of mule deer moved under the highway rather than over (H. Sawyer, personal communication). Regardless of the specific type of crossing structure, appropriate implementation can reduce mule deer highway mortalities.

Table 1. Estimated costs associated with deer-vehicle collisions. To allow for comparison, all values were adjusted using the CPI inflation calculator to 2013 USD (Bureau of Labor Statistics 2013).

Study	Vehicle Repairs	Human Injuries	Human Fatalities	Value of Deer	Carcass Removal	Towing & Accident Investigation	Total
State Farm 2013	$3,414	NA	NA	NA	NA	NA	$3,414
IIM 2012	$2,142	NA	NA	NA	NA	NA	$2,142
Huijser et al. 2009*b*	$2,862	$2,949	$1,094	$127	$55	$136	$7,222
III 2009	NA	NA	NA	NA	NA	NA	$3,274
Huijser et al. 2008	$2,002	$2,939	$1,817	$2,175	$54	$140	$9,127
Bissonette and Kassar 2008	$1,471	$75	$2,000	$227	NA	NA	$3,773
Schwabe et al. 2002	NA	NA	NA	NA	NA	NA	$3,413
Romin and Bissonette 1996	$2,807	NA	NA	$2,191	NA	NA	$4,998
Hansen 1983	$2,043	$18	$241	NA	NA	NA	$2,302
Reed et al. 1982	$1,796	NA	NA	$1,440	NA	NA	$3,236
Mean	$2,317	$1,495	$1,288	$1,232	$54	$138	$4,290

Photo courtesty of Tim Torell

Table 2. A review of studies that have evaluated the selection of habitat by mule deer with respect to roads.

Study	Region	Season	Demographics		Scale of Selection	Road Type	Response
			Age	Sex			
Lendrum et al. 2012	NW Colorado	Spring Migration	≥1.5 yrs	Female	Within Study Area	All Roads	Avoidance/Affinity
Anderson et al. 2012	SE Idaho	Winter	≥1.5 yrs	Female	Within Study Area	All Roads	Avoidance/Neutral
Stewart et al. 2010	SE Idaho	Summer/Winter	NA	Female	Within Study Area	All Roads	Affinity
Long et al. 2009	NE Oregon	Parturition	> 2 yrs	Female	Within Study Area	All Roads	Affinity
Sawyer et al. 2009	W Wyoming	Winter	≥1.5 yrs	Female	Within Study Area	Traffic at Well Pads	Avoidance
Tull and Krausman 2007	SE Arizona	Annual	NA	Female	Within Home Range	Paved Roads	Affinity
Sawyer et al. 2006	W Wyoming	Winter	>1 yrs	Female	Within Study Area	Unpaved Roads	Avoidance
D'Eon and Serrouya 2005	SE British Columbia	Annual	NA	Male/Female	Within Study Area	Unpaved Roads	Neutral
D'Eon and Serrouya 2005	SE British Columbia	Annual	NA	Male/Female	Within Home Range	Unpaved Roads	Avoidance
Wisdom et al. 2004	NE Oregon	Spring/Summer	NA	Female	Within Study Area	All Roads	Affinity
Stewart et al. 2002	NE Oregon	Annual	NA	Female	Within Study Area	All Roads	Neutral
Johnson et al. 2000	NE Oregon	Spring/Summer	NA	Female	Within Study Area	All Roads	Affinity
Bowyer et al. 1998	NW California	Summer	2–10 days	Male/Female	Within Home Range	All Roads	Affinity
Rost and Bailey 1979	N Colorado	Summer/Fall	NA	NA	Within Home Range	All Roads	Avoidance

ISSUES

DIRECT EFFECTS

Several methods are commonly used to index the number of deer killed by vehicle collisions. Accident reports and insurance claims are popular methods used to quantify a minimum number of deer involved in vehicle collisions, because these data are readily available in most states. Carcass surveys involve driving roads to look for deer that have been struck by vehicles. This method is usually done in conjunction with collecting carcasses on or nearby roadways to reduce public safety concerns. Accident reports, insurance claims, and carcass surveys all underestimate the number of deer killed on roads. In Utah for example, carcass surveys accounted for only 41% of dead deer on or adjacent to roads (Bissonette and Olson 2013).

Bissonette and Olson (2013) compared these three approaches (accident reports, insurance claims, and carcass surveys) to determine which best estimated the number of deer killed on Utah roads. Accident reports estimated 2,004 mule deer were involved in vehicle collisions, whereas insurance claims estimated 5,374 mule deer were killed on roads. Carcass surveys estimated 5.26 and 1.96 times the number of deer involved in vehicle collisions than accident reports and insurance claims respectively and estimated an average of 10,541 deer killed on Utah roads annually. Thus, vehicle collisions killed between 2–5% of Utah's estimated population of 300,000 mule deer annually during 2008–2012.

The sex and age of animals killed also determine how vehicle collisions affect mule deer populations. Knowing these demographics is essential because population growth is mainly driven by adult female survival rates, production of fawns, and survival rates of fawns, with male survival contributing less (Gaillard et al. 1998, White et al. 2001). Additionally, prime-aged females have the highest survival and reproductive rates, and added mortality to this demographic segment will likely influence population growth rates (Robinette et al. 1977, Olson et al. 2014b).

In Utah, females comprised 65% of deer carcasses on roadways from July 2010–December 2011 (Olson et al. 2014b). Furthermore, 40% of deer carcasses were adult females, nearly all (98%) of which were 2–7 years old. Although these data indicate vehicle collisions could negatively affect population growth based on the high numbers of prime-aged females killed, these does were killed in proportion to their availability when compared to classification surveys conducted each fall. Bucks, however, were killed at a higher rate than their availability, which has less influence on population growth, but may limit future hunting opportunity (Olson et al. 2014b).

Bissonette and Olson (2013) proposed viewing vehicle collisions similar to having another predator in an ecosystem. For instance, Laundre et al. (2006) estimated mountain lions killed 2–6% of the mule deer population annually in southwestern Idaho, and Mitchell (2013) showed that 45–63% of mule deer killed by mountain lions in central Utah were female. Vehicle collisions and mountain lion predation were similar regarding mule deer mortality effects on population demographics in this study. When added to existing predation, the degree to which highway mortality is additive or compensatory is unknown.

Of all limiting factors for mule deer, vehicle collisions may be the most publicly evident because deer carcasses are highly visible on highways, the public is affected directly, and the media frequently reports on the topic. As a result, vehicle collisions are often perceived by the public to be an important limiting factor in deer population dynamics. However, determining the actual effect of vehicle collisions on mule deer populations is difficult to assess and varies by location, season, and year (Olson et al. 2015). Although deer vehicle collisions had a limited effect on the statewide deer population size in Utah (2–5% killed by vehicles), local populations (units with migrating herds, individual canyons, or specific winter ranges) may be substantially affected by vehicle collisions (Lopez et al. 2003, Peterson and Messmer 2011). The indirect effects of movement barriers (addressed below) have a substantially greater population-level effect on mule deer than direct mortality alone.

Probably the largest economic benefit associated with reducing collisions is the increase to human safety and decrease to financial costs. The cost of a collision with a deer is estimated to be $6,617 (Huijser 2009b), which

Photo courtesy of Nevada Department of Wildlife

includes property damage, lost hunting value, human injury, and human deaths (Table 1). With nationwide estimates of the frequency of an incident involving a large animal at 2–4/minute, the cost to society in general and insurance providers in particular are probably $7–14 billion annually.

INDIRECT EFFECTS

Fragmentation can have effects on mule deer populations that may not be considered by planners. In most states, mule deer populations are migratory and move between summer and winter ranges, sometimes as far as 150 miles (Carrel et al. 1999, Sawyer et al. 2013). In many instances, mule deer may not rely on these seasonal habitats every year, but severe winters or droughts can dramatically increase rates of mortality if these animals do not have access to those vital portions of their range. Even in areas where seasonal migrations are not common, roads, railways, developments, and canals can isolate mule deer from important components of their habitat.

Typically, mule deer will consume about 1–4 gallons of water/day depending on weather and exertion (J. Hervert, Arizona Game and Fish Department, personal communication). Prior to settlement, mule deer had access to natural springs, seeps, and streams. Many natural water sources have become compromised due to human water use. Consequently the quantity and distribution of natural water sources have been altered. Artificial water developments that trap runoff, take advantage of wells, or even capitalize on treated wastewater effluent have been used to provide this needed resource. Sometimes the placement of artificial waters has been controversial, especially when placed within federally-designated wilderness areas. Nevertheless, these waters are generally believed to favor mule deer distribution and abundance and mitigate when barriers fragment their habitat (McKee et al. 2015).

Access to other critical habitat components may be restricted similarly. This is particularly true in seasonal migrations, as summer range is often dominated by more herbaceous growth important to nutritional growth of young deer and improving body condition of adult deer, whereas winter range is often dominated by important browse species that ensure adequate nutrition to survive sometimes severe winters. Even without migrations, there may be times when forage conditions may be superior in nearby habitats due to differences in precipitation patterns or wildfire distributions and adequate access is important to optimizing diets.

Barriers may also influence breeding success and survival. Increasing evidence in genetic analyses has identified how seemingly small barriers to wildlife movement, such as fences, can reduce gene flow (e.g., Sprague 2010). Highways, canals, and railways may limit gene flow if adequate movement across these barriers is not possible. Although genetic inbreeding is rarely a problem with ungulates, genetic isolation could be addressed through translocations of breeding age males.

Photo courtesty of George Andrejko

RECOMMENDATIONS

IMPLEMENTATION

Implementation of any mitigating feature is best considered during the initial planning phases of a project. For many features like roads, railways, or canals, adding mitigation features such as fencing, enlarged culverts, or bridges large enough to readily facilitate mule deer movements requires extensive engineering. Attempting to insert mitigation features late in the planning phase is problematic and difficult. Consequently, early discussions with planners and engineers are critical for effective implementation. At these early discussions, existing telemetry and DVC data can be useful in determining where and what features may be considered. Telemetry data can be extremely useful in delineating likely crossing areas. This data can be expensive to obtain and may not exist during project planning. Occasionally, highway planners may be willing to fund crossing studies for some species. In other instances, accident report data indicating vehicle collision location and frequency can be an effective surrogate for crossing frequency (Coe et al. 2015).

Opportunities occasionally exist to retrofit existing structures to make them more likely to favor crossings of mule deer or other wildlife. These opportunities are frequently suboptimal and expensive, yet can reduce DVCs in some situations. Favorable cost-benefit ratios for implementation of this type of project can be more difficult to demonstrate because it does not generally systematically deal with a realized problem. Regardless of how a project is initially implemented, monitoring is essential to identify specific successes and shortcomings that may be replicated or avoided later.

MONITORING

Monitoring plays an important role in determining effective application of mitigating tools and efficacy of various tools post-implementation. Although the efficacy of various mitigation actions for increasing passage of mule deer has been documented, post-implementation monitoring remains an important and often overlooked component of many actions.

A formal post-construction monitoring plan should be developed concurrently with construction project planning, identifying where monitoring will occur, who will conduct the monitoring, who will install and pay for monitoring devices, how long monitoring will continue, and who will be responsible for reviewing and reporting monitoring results. Monitoring post-construction is necessary to determine effectiveness of mitigation actions, inform mitigation decisions for future projects, and identify areas where mitigation features failed to reduce collisions or possibly created new collision hotspots. In the absence of telemetry data, still and video cameras and track counts can be effective tools to determine if mule deer are using crossing structures. In addition to monitoring passage success of target wildlife, the post-construction monitoring plan should be designed to identify areas of increased DVCs within the larger project area For example, increased DVCs at the terminal ends of 8-foot fencing may warrant the need for additional signage or fencing.

Monitoring post-implementation can be useful to inform future decisions and identify where mitigating features failed to solve issues. Combining telemetry, structure use (camera or tracks), and road-kill data provide the best possible information to determine the effectiveness of a mitigation measure. Regardless of any formal monitoring plan, any increase in DVCs after implementation should increase monitoring to determine if and why a mitigation feature has become less effective.

EXCLUSION FROM ROADS AND RAILWAYS

Research and Specifications

Relatively few options exist for effectively excluding deer from roads and railways, although many options have been tested. These exclusionary systems can employ physical, visual, olfactory, or aural devices, or some combination (Putman 1997, Farrell et al. 2002, Romin and Bissonette 1996a).

Ungulate-proof fencing, which routinely involves woven-wire fencing, has proven the most effective physical means for reducing collisions with deer and other ungulates (Woods 1990, Clevenger et al. 2001a, Gagnon et al. 2010, Bissonette and Rosa 2012). Fence heights greater than 7 feet substantially reduce the likelihood that deer will jump over them (VerCauteren et al. 2010, Found and Boyce 2011a). Mixed results have been reported on the effectiveness of roadside fencing, especially where maintenance is lacking. Animals can crawl under fences or cross at the ends of fences, resulting in zones of increased incidence of wildlife-vehicle collisions (Puglisi et al. 1974, Falk et al. 1978, Feldhamer et al. 1986, Woods 1990, Clevenger et al. 2001a, Gulsby et al. 2011). Fencing is most effective when used in conjunction with wildlife crossing structures (i.e., underpasses and overpasses; Romin and Bissonette 1996a, Forman et al. 2003, Dodd et al. 2007a, Beckmann et al. 2010). Woods (1990) reported 94−97% reductions in wildlife-vehicle collisions involving ungulate species in Alberta with wildlife crossing structures and fencing, while Clevenger et al. (2001a) reported an 80% reduction in ungulate-vehicle collisions, also in Alberta. Ward (1982) and Sawyer et al. (2012) reported a more than >90% and >80% reduction respectively in collisions with mule deer where underpasses and fencing were applied in Wyoming. As an alternative to standard woven-wire fencing, electrified fencing has shown favorable results for ungulate species and can be less expensive in some cases (Seamans and VerCauteran 2006, Leblond et al. 2007, Gagnon et al. 2010).

Another consideration when building fences for roads and railways is how to prohibit deer entry at lateral access roads. Gates are the most effective, but may be left open inadvertently (Sawyer et al. 2012). On lateral access roads with higher traffic, extra wide cattle guards, deer grates, or electrified barriers (e.g., electrified mats or electrified roadways) can help to reduce deer access while allowing uninhibited vehicular access (Reed et al. 1974a, Belant et al. 1998, Seamans and Helon 2008, Allen et al. 2013). In the event that deer gain access to the road, methods to allow wildlife out of the fenced area are essential. One-way gates that allow deer to exit the road without reentering were originally recommended (Reed 1974b), however more recently, jump-outs or escape ramps have become a more popular method for allowing large ungulates to escape from fenced roadways (Bissonette and Hammer 2008, Siemers et al. 2013).

Many different devices have been used to attempt to modify deer behavior through their senses (Huijser et al. 2008). To use vision as a warning cue to deer of oncoming vehicles, wildlife warning reflectors that cause a beam or reflection directed toward animals when cars pass have been tested on several occasions, and although some gray literature studies showed positive results, most peer-reviewed studies concluded they were ineffective or results were inconclusive at best (Waring et al. 1991, Reeve and Anderson 1993, Ujvári et al. 1998, D'Angelo et al. 2006). Strieter (2008), maker of Strieter-Lite reflectors, identified potential flaws and favorable results in some studies of reflectors and concluded that further investigation of these tools devices may be warranted for mule deer.

Use of deer olfaction and taste in attempts to exclude deer from roadways can be employed through repulsion or attraction. Repulsion entails using scents and tastes that cause wildlife to avoid an area, whereas attraction uses these same senses to draw or hold wildlife to a specified area. Planting species that are not palatable to deer can reduce their desire to feed along roadsides, and products that invoke a repulsive response in deer can add an additional deterrent effect. Palatable species may be planted or water made available to draw deer away from roadways. Attraction can include intercept feeding, which has showed some favorable results for a short-term solution for mule deer but seemed less promising for the long term (Wood and Wolfe 1988). These methods can be time consuming and expensive as plant growth and precipitation reduces effectiveness, requiring continual maintenance and application (Farrell et al. 2002, Huijser et al. 2008).

Benefits and Challenges

Although fencing is the most effective method to reduce deer access to roads and railways, wildlife crossing opportunities are necessary to reduce loss of habitat connectivity. Knowing where to terminate fencing is important as wildlife may enter around the terminal ends of the fencing and increase collisions at that location (Bellis and Graves 1978, McCollister and van Manen 2010, Gulsby et al. 2011). Where possible, fences should extend well beyond probable crossing areas to reduce the likelihood that mule deer will simply move around the terminal ends (Ward 1982, Bissonette and Rosa 2012). Although transportation department rights-of-way routinely extend for several hundred feet on either edge of a highway, the exclusionary fencing should taper to a narrow opening at the terminal ends to help reduce the probability of ungulates entering the stretch of highway with exclusionary fencing. Ungulate proof-fencing is costly and requires substantial maintenance (Forman et al. 2003), potentially contributing to reluctance on the part of transportation managers to fence extensive stretches of highways. Maintenance expenses must be considered when promoting exclusionary fences. Properly maintained fencing when accompanied by wildlife crossing opportunities, lateral access road devices, and escape mechanisms can create a system that allows wildlife passage while reducing collisions (Sielecki 2007).

Financial Assessment

Standard woven-wire ungulate-proof fences are by far the most effective method to reduce deer access to roads and railways. Costs can vary greatly among projects and are generally driven by a combination of material prices, contractor competition, and size of project. For example between 2002–2013 several projects in Arizona that used similar 8-foot-high woven-wire fence with metal line posts ranged from $11–40/linear foot or $58,080–211,200/mile. This variability in cost can substantially influence a state department of transportation's capability to install fencing where it is warranted. In addition, requirements for exclusionary devices at heavily used lateral access roads and exit devices for deer that are trapped within the right-of-way can cost several thousand dollars each. Maintenance costs must be considered as well and may exceed construction costs. The greater the structural integrity of the initial investment, the lower the long-term maintenance costs will be. Other less effective methods such as visual and olfactory cues can be a fraction of the cost, yet, due to their lack of demonstrated efficacy, their use as a sole deterrent may be ill advised.

LIVESTOCK FENCING DESIGN AND ALTERNATIVES TO FENCING

Research and Specifications

Fences have become a predominant feature on the landscape throughout the West. Most fences are built to contain livestock within pastures or range allotments or exclude them from crops, buildings, roadways, and residential areas. Fences that limit or direct movement of big game may be necessary to protect crops, and some fences exist primarily to delineate property boundaries. Although these fences are not usually intended to restrict deer they can impede seasonal migration or daily movements, especially if fawns cannot negotiate them. Both fawns and adults can get caught in wire fences and die because they cannot free themselves or from injuries sustained in getting free.

Fences, particularly right-of-way fences on roadways transecting migration corridors, cause a substantial amount of mule deer mortality if they are not adequately designed to exclude all ungulates (Harrington and Conover 2006). Many fence designs are especially dangerous to mule deer because they entrap or entangle their legs when a deer attempts to jump over a fence. Harrington and Conover (2006) documented the majority of mule deer mortalities were caused by animals getting entangled in wire fences, particularly within the top 2 wires. Most lethal were woven-wire fences (short enough to jump over) with a single top wire. They observed the highest mortality during August when fawns were being weaned and were far more likely than adults to die in or near a fence. Substantial mortality in this study resulted presumably when fawns were separated from maternal care because the fawn was incapable of negotiating a fence crossing after the maternal doe had. They found that 70% of all fence-related mortalities (mule deer, pronghorn, and elk) were from fences >40 inches high, but < 7 feet high, regardless of fence type. Fences should be of sufficient height and structure to exclude all ungulates or short enough to permit unfettered crossing. Bottom strands placed at least 16 inches above the ground allow crossing beneath the fence.

Before building a fence, consider whether a fence is necessary or if an alternative to fencing may be employed, such as virtual fencing or virtual herding (Anderson 2007). If a fence must be built in mule deer habitats or migration corridors, then several factors need to be considered: purpose of the fence, mule deer abundance, daily or seasonal movements of mule deer, and presence of fawns (i.e., season of use). Some fence designs have been developed to reduce effects to mule deer and other wildlife (Paige 2012). Spacing between top wires, on fences using single strands of wire, is very important because of the manner in which mule deer jump over fences. Mule deer draw their legs under their bodies as they leap over a fence. If 1 or both hind legs fail to clear the top wire, the legs may catch between the top 2 wires. In that scenario, the wires twist tightly, entangling the lower portion of the leg or legs, resulting in serious injury and often death. Fences built on slopes are especially problematic; a fence of any height is more difficult to jump when approached from downhill because effective fence height is increased. Approaching a fence from the downhill side on a 30% slope increases the height by 20 inches (Paige 2012). On steeper slopes, fences become more challenging for mule deer to jump without injury or death.

Any fence will create some impediment and risk to mule deer and other wildlife. However, some fence configurations reduce negative effects. Height of a barbed or smooth-wire fence on mule deer range should not exceed 40 inches (Harrington and Conover 2006). Space between the top 2 strands should be at least 12 inches. The bottom strand should be smooth (no barbed) wire and should be at least 16 inches above the ground to allow fawns to pass underneath. Woven-fences should be avoided because they completely block mule deer fawn movement. If a woven-wire fence is required, the total height should not exceed 38 inches; these fences are more likely for deer to become entangled and should be avoided. The use of fence stays between posts is advisable to keep wire spacing consistent and reduce the likelihood of strands twisting in the event that an animal collides with the wire when crossing. There are a variety of other fence configurations that reduce effects to mule deer. Fences with seasonal “drop down” or adjustable height sections (sections of fencing wire are raised or dropped) or extra gates left open are especially useful in areas where mule deer migrate. Also, shorter electric fences effectively contain livestock and are more readily negotiated by mule deer. In addition to fence design, knowledge of wildlife movement, geography, topography, and snow accumulation patterns are important considerations when determining fence location. Certainly avoiding fences altogether, or at least more restrictive designs, in areas of known mule deer movement reduces deer mortality and eliminates barriers to

Photo courtesty of Tim Torell

essential movements, unless the fence is needed to guide wildlife into safe movement corridors.

Benefits and Challenges

Fences have been constructed in the West since the nineteenth century and have a long history of usefulness, controversy, and debate. Early rangeland fences were constructed to manage livestock movements. Today fences are still built primarily to manage livestock, and their utility and challenge continue to be debated. Strictly from a wildlife perspective, fewer fences will allow mule deer and other wildlife to move freely within and between important habitats and avoid unnecessary mortality.

Fencing is a necessary tool to manage livestock and maintain benefits to forage and water resources from unregulated grazing. New technology is in development to manage livestock movement, although none is currently viable across broad landscapes. Until technological advances increase, fence construction should be avoided in known mule deer migration corridors; if fence construction cannot be avoided, then considerations for access through or around enclosed areas are necessary. If exclusion is not essential, features like underpasses or overpasses, drop down fences, gates, and non-traditional fence designs (e.g., electric fence) may allow animal movement.

Financial Assessment

Fencing costs vary depending on area and availability. High-tensile electric may be the least expensive and costs about $5,000/linear mile to purchase and install. Barbed wire fences are estimated to cost about $7,500/linear mile, whereas woven-wire fences (4 feet in height) cost about $10,000/linear mile. Annual maintenance costs average between $800–1,600/linear mile depending on the type of fence, environmental variables, and labor costs. Many states have programs that provide incentives to reduce the cost for landowners to implement appropriate fencing.

MOTORIST WARNING DEVICES, INCLUDING SIGNS, CROSSWALKS, AND LIGHTING

Research and Specifications

Many options to reduce motorist speed or alert motorists of potential for DVCs are available (Romin and Bissonette 1996a, Putnam 1997, Farrell et al. 2002). These range from static signs that reduce speed limits to technologically-advanced animal detection systems in which signs are activated only when wildlife are present. The intent behind all motorist warning systems is to alert the driver to potential hazards with wildlife on the roadway and cause the driver to slow enough to completely avoid a collision or collide at a slower speed to reduce the severity of the accident (Huijser et al. 2009a).

Permanent signs are likely the earliest form of motorist warning to reduce wildlife-vehicle collisions. On many roads, departments of transportation have placed signs with silhouettes of wildlife in an attempt to forewarn motorists of potential for collisions with wildlife. Little research has been conducted on effectiveness of permanent signs, however there is a general consensus that they are ineffective for long-term mitigation of DVCs because motorists tend to largely ignore them. If permanent signs are used, placement should focus on high DVC area to reduce motorist complacency (Pojar et al. 1975, Knapp and Yi 2004, Found and Boyce 2011b). Temporary signs appear to be more effective than permanent signs as signs are in place for a shorter period of time, increasing the likelihood for motorists to note and react to new signage. Sullivan et al. (2004) documented a 50% decrease in collisions with mule deer during migrations using temporary warning signs with flashing lights along 5 highways in 3 different states. Hardy et al. (2006) also reported that portable dynamic message signs were more effective at reducing driver speed than permanent signs along I-90 in Montana.

Signs that are activated by wildlife should be the most effective at reducing motorist speeds because there is limited opportunity for motorists to become habituated to them. Animal detection systems have been in existence since the late 1970s, and their performance has varied. Ward et al. (1980) documented a 100% reduction in DVCs, although their data was limited. Huijser et al. (2009a) tested various models of detection systems and found that their reliability was influenced by a range of environmental conditions. Detection systems that cover large expanses of road and require many signs and detection devices fail more often due to environmental factors such as vegetation, rain, and snow. Overall, many systems have been tested in field settings and most were unreliable, producing substantial false positives or negatives (Huijser and McGowen 2003). The systems that were most effective were used on lower traffic volume roads and combined with fencing to limit wildlife access to the road at a finite location. This reduced the potential for electronic malfunction (see below; Gordon et al. 2004, Gagnon et al. 2010). Recent studies in Arizona on animal-activated systems that include technologically-advanced software which acquire and identify specific targets before signaling their presence have had fewer incorrect classifications; electromagnetic sensors are still being tested in Colorado. Remote detection and warning of wildlife at roadways remains an area of active research and development.

Wildlife “crosswalks” are a combination of fencing and gaps in the fence that allow animals to cross roadways at designated areas. Crosswalks have been minimally tested, though Lehnert and Bissonette (1997) reported moderate effectiveness of crosswalks along 2 and 4-lane highways in Utah. These crosswalks included static or continuously activated signs warning motorists of crossing mule deer. Although they documented minimal motorist response, likely due to motorists becoming accustomed to and ignoring static or continuously-activated signs, there was still a decrease in mule deer mortality. Gordon et al. (2004) documented a minimal reduction in speeds, overall about 4 mph with the animal activated motorist warning signs

Photo courtesty of Wayne Wakkinen

road show little benefit in reducing DVC. Overall, animal detection systems have the potential to be an effective tool in mitigating DVC (Huijser and McGowen 2003). However, in many cases they do not reduce DVCs, primarily due to environmental conditions that cause system failures that lead to excessive false positives, in turn causing motorists to ignore the warning signs, or false negatives that fail to inform the driver of an animal in the road (Huijser et al. 2009a). Further research on new technologies and devices that overcome these environmental factors is warranted. When working with transportation agencies on mitigation measures to reduce DVC, it is essential to selectively recommend methods that have a high potential for success. Failure to meet this goal can cause reluctance by transportation agencies to spend time and funding on potential solutions in the future.

along US Highway 30 in Wyoming. When a deer decoy was visible to approaching motorists in combination with the flashing lights, speeds decreased by up to 12 mph. Gagnon et al. (2010) documented a 97% decrease in elk-vehicle collisions and a nearly 10 mph reduction in motorist speeds at a crosswalk with animal-activated motorist warning sign. Crosswalks can function as an at-grade wildlife crossing in some circumstances, but they should not be used on high-speed highways (Gordon et al. 2004, Gagnon et al. 2010). When using crosswalks in lieu of other wildlife crossings, similar requirements for spacing between crosswalks along the roadway should be considered. Traffic volumes must be taken into consideration for crosswalks as high traffic can provide an impermeable barrier.

Speed reduction zones in areas where wildlife-vehicle collisions occur can reduce potential for more severe accidents. Enforcement of speed limits is key to their success as many motorists ignore speed limit signs. In general, speed reduction zones are considered ineffective at reducing DVCs (Romin and Bissonette 1996a, Bissonette and Kassar 2008). Highway lighting is an ineffective method to reduce DVCs (Reed and Woodard 1981, Romin and Bissonette 1996a). Anecdotal information indicates that highway lighting can cause areas beyond the lighting to appear even darker to motorists, reducing detection of deer once leaving the lighted area.

Benefits and Challenges

Accurate animal detection systems that reduce motorist habituation combined with funnel-fencing to restrict detection coverage area are effective at reducing motorist speed and alertness (Gagnon et al. 2010). Animal detection systems by themselves when deployed across large expanses of

Financial Assessment

Motorist warning systems can be relatively inexpensive, yet they are ineffective in many cases. Animal detection systems that provide warning to motorists only when deer or other wildlife are present are the best solution when wildlife crossings are not an option. If possible the warning systems should be combined with funnel fencing and electrified mats, which restrict possible movements of wildlife while crossing the roadway, to reduce potential for malfunction due to environmental conditions. The actual expenses for these types of systems may run from $50,000 to $200,000 depending on complexity and design. Costs for the regular maintenance of the warning system may additionally include full time staff or a private contractor to regularly check on these systems.

UNDERPASSES AND OVERPASSES

Research and Specifications

Wildlife crossings (underpasses and overpasses), when combined with funnel-fencing, have been widely recognized as the most effective method to simultaneously reduce wildlife-vehicle collisions while maintaining habitat connectivity (Ward et al. 1980, Clevenger and Waltho 2000, Dodd et al. 2012, Sawyer et al. 2012). Wildlife crossings are designed so that wildlife can pass safely over or under roads, removing wildlife from roadways, and reducing the effect of traffic on wildlife movements (Gagnon et al. 2007a, b; Dodd and Gagnon 2011). The numbers of wildlife crossings throughout North America are numerous and continue to grow (Bissonette and Cramer 2008).

Underpasses provide mule deer and other wildlife the opportunity to pass below the highway while allowing

traffic to pass overhead. Underpasses and culverts in many cases dually facilitate wildlife and water flow. Underpasses are generally considered the larger of the 2 types and are used to bridge larger areas like rivers and canyons, whereas culverts generally comprise smaller, fully or partially precast concrete or metal pipe better suited for smaller creeks or washes.

Research on the effectiveness of underpasses to safely pass mule deer began in the mid-1970s (Reed et al. 1975, Ward et al. 1980). Underpasses of various sizes and shapes have been shown effective for mule deer passage, but recommendations on optimal size are an ongoing and heavily-debated topic, particularly given cost restraints usually placed on construction projects. Openness ratio ((width x height)/length) is a commonly used term describing wildlife crossings, and many wildlife species prefer to pass through more open structures that appear shorter in length than those that are perceived as long, narrow tunnels. There is conflicting data on the optimal openness ratio for mule deer from recent research and understanding of wildlife behavior (Reed et al. 1975, Foster and Humphreys 1995, Jacobson et al. 2007, Schwender 2013), but width seems more important than height (Foster and Humphrey 1995, Clevenger and Waltho 2000, Cramer 2013) and length is likely even more important than width (Clevenger and Waltho 2000, Cramer 2013). Most studies on mule deer use of underpasses indicate that mule deer are more reluctant to use narrower structures than wider structures. Current studies, specifically for mule deer, indicate that minimum size for underpasses should be 8–10 feet in height and a minimum of 20 feet in width (Gordon and Anderson 2004, Cramer 2013), while length should not exceed 120 feet if possible (Cramer 2013). In areas where underpasses exceed 120 feet, such as 4-lane divided highways, providing an open median may help increase mule deer crossing success by reducing the overall length into 2 shorter sections (Foster and Humphrey 1995, Gagnon et al. 2005). These measurements are considered minimum requirements for mule deer, and planners should develop more open structures where possible to help ensure success of the underpasses. Where possible, culverts should have earthen bottoms to eliminate echoing and provide natural footing. Earthen fill between the top of the culvert and the road is also useful to reduce sound and vibration when vehicles pass overhead. Rip-rap (large rocks used to dissipate water flows) may be used in small amounts to help reduce regular erosion, but a natural soil pathway must be available for wildlife to navigate through the structure. Another method being implemented in Nevada is placing a rip-rap layer under several inches of native soil that will protect the structures during larger storm events, while providing a natural pathway for wildlife. After a large storm event the earthen pathway may require maintenance, but the overall structure will remain stable. In some instances, uncovered rip-rap can be used to guide wildlife into the desired pathway.

Because of their cost, overpasses are used relatively infrequently when compared with underpasses. Although overpasses have been implemented throughout North America for many wildlife species (Clevenger and Waltho 2005, Olsson et al. 2008), relatively few studies have evaluated mule deer use of overpasses until recently. Prior to 2000, only 5 wildlife overpasses existed in North America and limited data are available to evaluate the effectiveness of overpasses. The first wildlife overpass in North America was constructed in Utah along I-15, and is only 21 feet wide. Recent studies show that this 30-year-old overpass successfully facilitates mule deer movement (Cramer 2013). In British Columbia, the 19-foot-wide Trepanier overpass was built to facilitate wildlife movement over the Okanagan Connector (Highway 97C), and use by mule deer has been documented for this structure (Sielecki 2007). In Banff National Park, Alberta, Canada, overpasses were built primarily for the safe passage of grizzly bear across the Trans-Canada Highway, and mule deer benefited from these structures. Of 15 structures for mule deer to select from, 67% of all crossings by deer (mule deer and white-tailed deer

Photo courtesty of Wyoming Department of Transportation

combined) occurred at the 2 160-foot-wide overpasses (Clevenger and Waltho 2005).

Mule deer will use both overpasses and underpasses, and learn to use them more over time. Recently, studies to evaluate mule deer use of overpasses along US 93 in Nevada documented >13,000 crossings in a 2-year period (Simpson 2012), with >35,000 crossing in the first 4 years (N. Simpson, Nevada Department of Transportation, personal communication). Simpson (2012) found that mule deer preferred overpasses to underpasses, especially in the first years following construction. Mule deer continued to adapt to the underpasses over time. A recent Wyoming study found mule deer preferred crossing US 191 through underpasses rather than overpasses. This study included 2 sites, each with 1 overpass and 3 underpasses, and documented 60,000 mule deer and 25,000 pronghorn crossings in 3 years (H. Sawyer, personal communication). Three overpasses completed along the Trans-Canada Highway in Yoho National Park in 2011 will benefit mule deer along with other species. At this time, overpasses that would facilitate mule deer passage are also planned or under construction in Washington along I-90 and Nevada along I-80, which includes an overpass of 200 feet in width. As the number of overpasses and underpasses increase in mule deer habitat, evaluation of their effectiveness will provide insight to optimal design.

Photo courtesty of Wayne Wakkinen

Proper placement of wildlife crossings (underpasses and overpasses) is essential to ensure mule deer encounter them during daily or seasonal movements (Gagnon et al. 2011a, Sawyer et al. 2012, Coe et al. 2015). Along large stretches of road, spacing of wildlife crossings needs to be considered. Underpasses need to be close enough together to allow mule deer to encounter them within a reasonable distance. Bissonette and Adair (2008) recommended that wildlife crossings be placed about 1 mile apart for mule deer in areas where deer are frequently hit or regularly cross. Coe et al. (2015) noted that crossings could be placed more irregularly based on actual mule deer migration corridors or data that indicate high DVC areas. Similarly, escape ramps should be placed frequently enough that deer and other ungulates trapped inside fencing can escape the right-of-way before collisions occur.

Ungulate-proof fencing is likely the most important factor in the success of wildlife crossing structures. When properly designed and located, fences funnel deer towards crossing structures helping to overcome any minor flaws in design and placement. In most cases mule deer will not immediately use crossing structures and a learning period will be required (Gagnon et al. 2011a, Sawyer et al. 2012). For example, along US Highway 30 in Wyoming, mule deer took about 3 years to fully adapt to underpasses and fencing (Sawyer et al. 2012). Migratory mule deer are more likely than resident mule deer to use smaller underpasses, when combined with fencing, because of their need to move to seasonal ranges. Installing larger underpasses and culverts will increase permeability, whereas smaller structures increase the likelihood that mule deer may avoid the designed crossing. In areas with reduced permeability, mule deer will find other areas to attempt crossings, such as the end of the fence, jump outs, or small gaps.

Highway retrofitting has been used increasingly to reduce wildlife-vehicle collisions while maintaining habitat connectivity (Gagnon et al. 2010, Cramer 2013). Retrofitting typically employs fencing to funnel wildlife to existing structures that are suitable for wildlife passage. This would include bridges and culverts that already facilitate water flow, but in some cases can include low use roads (Ward 1982). In many cases, implementation of highway construction projects may not occur for decades, and retrofitting can provide a temporary solution. When retrofitting existing structures, each crossing structure must be acceptable for mule deer use; improper combinations of fencing and inadequate crossing structures will completely inhibit mule deer movement across the highway corridor.

Benefits and Challenges

Properly designed and located wildlife crossings with funnel fencing will ultimately provide the most effective method for reducing collisions with mule deer, and other wildlife species in the area must be considered as well. For example, elk generally use similar habitats as mule deer, but may be reluctant to use structures that mule deer

may readily use (Dodd et al. 2007b, Gagnon et al. 2011a, Cramer 2013). When dealing with mule deer collisions and connectivity in areas where there are elk present, designs for elk should be considered which will allow effective use by both species. Another consideration is smaller wildlife that reside in the area. Although recommendations for mule deer provide for about 1-mile spacing between structures, other smaller wildlife may not travel as far to locate a safe crossing opportunity, which may make the roadway a more substantive barrier for these species (Bissonette and Adair 2008). Allowing access to culverts too small for ungulate use may help to facilitate habitat connectivity for some of these smaller species (Clevenger et al. 2001b).

Financial Assessment

Wildlife crossings with ungulate-proof fencing are in many cases the most expensive solution, but they are by far the most effective. Culverts generally are the least expensive and can be installed for about $200,000, whereas overpasses and bridges can cost $2–10 million. Sufficient excess fill must be available to maintain grade and install enlarged culverts, or the highway must be raised by obtaining and hauling fill, an alternative so costly as to be prohibitive. Underpasses are usually more practical for transportation departments when they are located in drainages where water flow already requires such an accommodation. Costs to upgrade underpasses in these situations are somewhat less. Overpasses are generally designed solely for wildlife and expenses can be harder to justify. In general, overpasses are 4 to 6 times more expensive than underpasses. In some situations topography may not be conducive to underpasses and overpasses may be the only option. When considering placement of wildlife-dedicated overpasses, using natural ridgelines where the roadway cuts through a terrain feature can help reduce costs associated with substantial fill requirements. Retrofits of existing structures may be among the least expensive solutions for collision reduction and connectivity for mule deer if adequate terrain features exist.

Nevada observed a 50% decrease in the number of DVCs with each subsequent migration in a single location until the numbers reached ≤2 reported collisions/migration (Simpson et al. 2012). Additionally, an analysis of expenses on the same set of crossing structures showed a financial benefit of $1.58 for every $1.00 in cost for these features (Attah et al. 2012). With the observed decrease in the number of DVCs, and the positive benefit-cost score, the cost of the construction will be recuperated by taxpayers, insurance companies, and management agencies because of the decrease in human injuries and infrastructure damage (McCollister and Van Manen 2010).

NIGHTTIME AND SEASONAL SPEED LIMITS

Research and specifications

Speed is a factor that influences the probability of collisions in general. At slower speeds, motorists generally have more time to detect, identify, and react to obstacles in their path than if they were travelling at greater speeds. Yet studies that attempt to document the relationship between DVC and posted speed limits provide mixed results and generally do not confirm a relationship (Bissonette and Kassar 2008). Reasons for these mixed results stem from the limited relationship between actual speed with posted speed limit (Bashore et al. 1985) where DVCs are common. Roadway characteristics, deer behavior, deer distribution, landscape, and environmental factors have a greater influence on deer-roadway interactions regardless of posted speed limit (Bashore et al. 1985, Finder et al. 1999, Farrell and Tappe 2007, Found and Boyce 2011a, Lobo and Millar 2013). With these overriding factors in mind, strategic use of speed limit reduction during discrete deer movement periods and in locations of concentrated DVC may provide positive results. Temporary warning signs can be effective when used on roads with concentrated DVC peaks and isolated to narrow corridors. Motorists can become complacent with static signage over time (Sullivan et al. 2004). Periodic use of portable message signs can help overcome driver complacency and reduce vehicular speeds more than permanent dynamic message signs (Hardy et al. 2006). Providing a message identifying shorter distances to watch for deer can increase driver attention span for those distances (Hardy et al. 2006). Like most deer species, mule deer are generally crepuscular with increased movements during dusk and dawn. Deer often migrate seasonally, so reducing speed limits at times of the day or year when deer are most active may reduce the probability of wildlife-vehicle collisions. Regardless, given that increased vehicular speeds correlates with increased accident severity and property damage, strategically placed signs both temporally and spatially may ultimately save human lives.

Benefits and challenges

Traffic signage identifying appropriate speed is relatively inexpensive to implement. Enforcement can be difficult, and compliance for most highway signage is variable. If seasonal changes are needed to deal with migration periods, signage can be adjusted with minimal effort. Temporary dynamic message signs work better than standard static speed limit signs (Hardy et al. 2006). Lawful determination of appropriate speed limits can require administrative review and approval.

Logically, reducing vehicle speed should similarly reduce wildlife-vehicle collisions. Yet wildlife often cross unexpectedly, making reduced speed limits less effective in avoiding collisions. For instance, bighorn sheep have a relatively high rate of collisions with vehicles along US Highway 191 in southeastern Arizona (Wakeling et al. 2007) even though the roadway precludes high rates of speed and allows for good visibility. This winding section of US Highway 191 keeps vehicles from exceeding about 35 mph, whereas other nearby sections can be traversed at 55 mph and wildlife vehicle collisions are not correspondingly higher. In this situation, the proximity and juxtaposition of suitable habitat increases the likelihood that bighorn sheep will frequent and cross these roadways.

Additionally, motorists tend to ignore frequent signage

designating slow speeds if the roadway itself is suitable for faster traffic. Motorists tend to respond to signs that alert them through specific stimuli, such as flashing lights that only exhibit the stimuli when a particular threat initiates it. Gagnon et al. (2010) noted a nearly 10-mph speed reduction and a 68% increase in motorist braking response over multiple years when warning signs were activated by wildlife at the end of a 3-mile stretch of exclusion fencing. Frequent, static signs that simply note "wildlife crossing" are often ignored, and low speed limits on good roadways (with high frequencies of wildlife crossing attempts) are often overlooked as well. Seasonal signs noting deer or elk migrations are more effective in some instances. Vegetative plantings in highway rights-of-way sometimes attract or obscure wildlife and contribute to causes for wildlife-vehicle incidents.

Colorado experienced the confounding effects of implementing reduced speed zones to amend motorist behavior along a 100-mile section of highway with 14 experimental wildlife speed reduction zones. While data showed a minor improvement on average accident history throughout the total treatment area, 6 of the 14 segments (43%) exhibited worse accident history following implementation. Based on the inconclusive data, Colorado Department of Transportation removed the signage because changing driver behavior was found to be ineffective with the program (Colorado Department of Transportation, unpublished data). Both wildlife agencies and state departments of transportation agree that reduced speed limits are not particularly effective at influencing wildlife-vehicle collisions (Sullivan and Messmer 2003).

Financial assessment

Expenses associated with changing highway speed limit signage are relatively minimal. The administrative cost of the appropriate review and authorization for changes in speed limits is generally higher than that of simply changing out signs. As noted earlier, animal detection systems that provide warning to motorists, like temporary changes in speed limits, only when deer or other wildlife are present are the best solution when wildlife crossings are not an option. The actual expenses for these types of systems may run from $50,000 to $200,000 depending on complexity and design. Costs for the regular maintenance of the warning system may additionally include full time staff or a private contractor to regularly check on these systems.

Less expensive is temporary flashing portable signage that may be used seasonally, but costs may still approach $10,000 to implement. Simply changing static speed limit signs are inexpensive, yet ineffective in reducing DVCs.

DECOY DETERRENTS

Research and specifications

Decoy deterrents are intended to make motorists react to the visual cue of seeing the decoy and respond by slowing down. Research evaluating the effects of deer decoys as a stand-alone deterrent for DVCs is lacking, but several studies have evaluated decoys or simulations used in conjunction with other techniques. Using a cross section of a full-body taxidermy mount, Reed and Woodard (1981) evaluated deer simulations and highway lighting as a potential means to reduce deer vehicle collisions in Colorado. They found that highway lighting did not affect the location of deer crossings, location of accidents, nor mean vehicle speeds. The presence of a deer decoy placed in the emergency lane in lighted view of oncoming traffic, however, decreased mean vehicle speeds by 8.7 mph.

In Wyoming, Gordon et al. (2004) evaluated the effectiveness of the FLASH™ (Flashing Light Animal Sensing Host) system, designed to detect deer presence on the highway and warn motorists by triggering flashing lights associated with a sign. In addition, they experimentally tested various treatments involving the sign, the lights, and the presence of a deer decoy (full-body taxidermy mount of a mule deer doe). Automobiles traveling in the day failed to reduce speeds substantially in response to the activated system, however, speeds at night were reduced an average of 4 mph. Speeds were reduced an average of 12.5 mph in response to flashing lights and a deer decoy placed along the highway.

Photo courtesy of P. Cramer

Photo courtesty of Tim Torell

Benefits and challenges

The limited published research and lack of published management protocol on the use of deer decoys to deter vehicle collisions presents challenges for evaluating their efficacy. Research suggests that vehicles will reduce speeds in presence of deer decoys, but duration and actual application of the technique needs further evaluation. Reed and Woodard (1981) observed brake lights on 51% of the vehicles approaching the deer decoy during night, but evaluation was discontinued because of risk to motorists caused by 5–10% of the vehicles that either slowed drastically or stopped near the simulation. Placing decoys near roads could actually cause vehicle-vehicle collisions, placing substantial liabilities on management agencies that used them.

Financial assessment

Current costs of a full body taxidermy deer mount will range depending on location and taxidermist, but typically between $1,500–2,500. Simulated decoys are available for substantially less. The potential for accidents and injuries place a substantial liability on any agency that may choose to use this approach.

AUDITORY STIMULI

Research and Specifications

Several devices have been developed to stimulate an auditory response in deer to alter their behavior to avoid collisions with vehicles. “Deer whistles,” which are attached to vehicles and emit a high-frequency sound, are perhaps one of the most common of these devices used by motorists. However, contrary to popular belief, assessments of deer whistles indicated deer did not respond differently to vehicles equipped with whistles than to those that were not equipped (Romin and Dalton 1992, Romin and Bissonette 1996). Scheifele et al. (2003) tested several deer whistles and concluded they were likely to be ineffective based on several aspects of acoustic performance and deer auditory responses. Valitzski et al. (2009) tested vehicle-mounted devices that produced tones, similar to sounds produced by deer whistles, at 5 different frequencies. They found deer responses were not adequate to reduce collisions and concluded deer may not have adequate time to react as desired, may not have the ability (neurologically) to process the sound as an alarm so that they respond as desired, or may not perceive the sounds they tested as threatening. Ujvári et al. (2004) found deer demonstrated relatively quick habituation (≤10 days) to sounds of acoustic highway markers activated by passing vehicles. A stimulus system (high-pitched sound in combination with a strobe light) activated by vehicle headlights reduced wildlife-vehicle collisions by 85–93% in Austria (Huijser et al. 2008), but this effect has yet to be replicated.

Incorporation of alarm or distress calls in an auditory stimulus system designed to reduce collisions may warrant additional investigation. Use of such bioacoustics to reduce deer presence in areas of highly preferred forages (e.g., crops, orchards) has produced mixed results. In some cases, deer easily became habituated to bioacoustics or the sounds were deemed ineffective (Belant et al. 1998, VerCauteren et al. 2005). However, Hildreth et al. (2013) documented a 99% reduction in deer entry into baited sites where deer-activated, bioacoustic frightening devices were deployed. Such systems may deter deer from crossing highways, but further testing is needed.

Benefits and challenges

Primary benefits of auditory stimulus systems are their relative simplicity and low cost. If appropriate sounds could be produced to effectively alter deer behavior in a desired manner, such systems could result in substantial reductions in DVCs. Challenges include lack of effectiveness (i.e., deer do not respond or do not alter their behavior as desired) and habituation of deer to the sounds (i.e., deer may respond as desired for a short time, but responses decline after repeated exposure).

Financial Assessment

Deer whistles and other auditory stimuli are relatively inexpensive, generally between $10–100. However, tests of auditory stimuli have been inconclusive or have shown that the devices were ineffective for reducing DVCs. A technical working group formed to evaluate mitigation methods for wildlife-vehicle collisions concluded neither research nor construction resources should be used for audio signals (in the right-of-way or on vehicles; Huijser et al. 2008). Given the high costs and liability associated with DVCs, advocating use of auditory stimuli devices as a sole deterrent to avoid collisions should be avoided.

COORDINATING AND FUNDING ROADWAY PROJECTS

Perhaps the most important consideration is integrating wildlife movement data and mitigation features into roadway project design prior to initiation of construction. While this seems logical, many biologists and wildlife agencies still find themselves responding to proposed projects rather than involving themselves during the planning phases. Historically, most highways were built during a time when wildlife concerns and DVCs were not considered, so existing roads must be approached based on problems that have been discovered since construction. New roadways are now more routinely investigated thoroughly and take wildlife and DVCs into consideration because of more recent experiences, NEPA processes, and safety concerns. Nevertheless, engagement by wildlife agencies remains essential to ensure that the best information is incorporated during the planning phase.

Federal highways and state roadways are frequently planned and developed decades before implementation. Highway departments can identify future roadway developments based on human population growth projections, and engineering and design generally precede implementation to develop realistic budget projections so that they may be included in congressional budget appropriations. Altering projects after work has begun can result in dramatic cost overruns that cannot be realistically accommodated.

During planning phases, departments of transportation are generally most influenced by existing data sets that demonstrate likely crossing areas with substantial information about the frequency and duration of wildlife crossings. In the absence of these data, information describing wildlife-vehicle collision frequency or data on road-kills may be used to identify likely crossings (Coe et al. 2015). Research has demonstrated similarity in patterns among data sources with several ungulate species (e.g., Wakeling et al. 2007, Gagnon et al. 2011b).

Each agency is tasked with specific legislative mandates. While conservation of wildlife is central to the mission of each wildlife agency, the various departments of transportation's main role is to provide a safe road network. Simply placing exclusionary fencing around each highway could meet this latter mandate, but fencing is not the complete answer from an ecological standpoint. Support from wildlife agencies has been pivotal in moving forward with some of the largest wildlife crossing and mitigation projects. Most departments of transportation rely on federal funding, which is targeted for the highest risk areas throughout the US. An area that is locally considered a priority may not be considered similarly from a national perspective. Consequently, creativity in securing funding from multiple sources for wildlife crossing and mitigation projects have proven critical in the successful implementation of many important projects.

SUMMARY

To effectively decrease DVCs, wildlife agencies and departments of transportation should identify and prioritize areas of greatest concern in their states to inform decision makers allocating limited resources (Ford et al. 2011, Polak et al. 2014). Collecting and mapping locations of collisions will allow wildlife managers and contractors to identify and properly document problem areas. Conducting this analysis at a statewide scale can potentially increase public safety, reduce property damage claims, and reduce mule deer mortality. If these areas are identified ahead of time, wildlife mitigation can be incorporated into larger projects and reduce overall costs.

Olson et al. (2014a) reported on an integrated smartphone-based system used to document wildlife-vehicle collisions, store information in a database, and query data. This mobile web application has been used for several years by the Division of Wildlife Resources and the Utah Department of Transportation. Both agencies have access to the database and share in the responsibility of collecting DVC information. Using this phone application has decreased data entry errors by 10%, increased efficiency in reporting, and has allowed both agencies to view and easily agree on problem areas in Utah. This type of data collection will reduce or eliminate spatial accuracy issues, providing high resolution information essential for informing management decisions (Gunson et al. 2009).

Planning processes for highway departments are long term, and a great amount of effort and resources are put into each highway project. As a result, wildlife agencies must provide input early in the developmental process. One way this can be accomplished is to become familiar with individual state department of transportation Statewide Transportation Improvement Programs (STIP), which is a process that identifies future highway projects. STIPs are required to obtain federal highway funding. As departments of transportation conduct scoping and other planning efforts for future projects, wildlife agencies can compare proposed construction plans with priority lists of high collision areas. Coordinating and planning for mitigation efforts is most effective at this stage of the planning process and will have a higher probability of being implemented if done within the framework of normal planning procedures.

Often, hotspots may occur on roadways that are outside of areas identified in the STIP, and other methods can be used to identify potential mitigation to reduce collisions. One of these is the completion of a corridor analysis study (these studies may not be part of a standard STIP). A corridor analysis focuses on a stretch of roadway that has been identified as having a high occurrence of wildlife-vehicle collisions. With the use of wildlife data sets such as collision data and mapped habitat layers, the analysis can identify opportunities for highway mitigation such as existing bridges and culverts, and potential locations for new structures. Utah has several examples of how completion of a corridor analysis can lead to successful highway mitigation. A Needs Assessment consists of a short report (4–8 pages) that identifies the problem area, quantifies the amount of collisions occurring within the stretch of roadway, and proposes various mitigation options that could be used (e.g., crossings, fencing, signage) to reduce them. This report is then submitted to the department of transportation for consideration. This process has led to several stand-alone wildlife mitigation projects being constructed in the past decade.

Wildlife agencies are responsible for managing healthy populations of mule deer, and departments of transportation have a responsibility to increase public safety on roadways. State highway departments and wildlife agencies share a common goal of reducing wildlife-vehicle collisions to increase public safety and reduce wildlife mortality. Including diverse stakeholders in the planning process allows for increased funding opportunities, momentum, and public support for DVC mitigation projects on highways.

Although multiple options exist to reduce wildlife-vehicle collisions, the most effective to date are highway overpasses and underpasses. Exclusionary fencing is essential to guide mule deer toward passages, but the fencing alone simply forms another barrier that limits movement, migration, and access to resources. This combination is the most successful in getting mule deer to cross virtually any movement barrier from canals to railroads. These mitigation strategies demonstrate positive cost-benefit ratios, but the fact remains that costs of implementation can be high and lead times prior to implementation can be long. Planners must be informed long before implementation, and funding must be committed to be successful. Investments in some commonly considered deterrents, like deer whistles and temporally enforced speed zones, may make the public falsely believe they are affecting human safety and mule deer survival, but are probably having no net effect on either. Other perceived deterrents, like placing decoys to alert motorists to the risk of free-ranging mule deer, may actually place humans at unnecessary risk of vehicle accidents.

Planning and implementation of adequate structures to reduce vehicle collisions with wildlife takes advance planning and suitable data. This advance planning requires that agency wildlife biologists communicate effectively with highway department planners decades in advance of project implementation. The most valuable information is animal movement data collected on multiple species using telemetry with global positioning system technology. However, do not discount road-kill counts or highway collision data to inform future actions. In absence of telemetry and road-kill data, expert-based corridor modelling can provide a viable solution for locating mitigation opportunities (Clevenger et al. 2002, Loe et al. 2015).

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