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Deer–vehicle collision prevention techniques

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Abstract. Every year in the United States approximately 1.5 million deer–vehicle collisions (DVCs) occur resulting in >29,000 human injuries, >200 human fatalities, 1.3 million deer fatalities, and >1 billion dollars worth of property damage. Despite the magnitude of this problem, there are relatively few well-designed studies that have evaluated techniques that can be used to reduce DVCs. Techniques to reduce DVCs fall into 4 categories: reducing the number of deer (*Odocoileus* spp.), reducing the number of vehicles, modifying deer behavior, and changing motorist behavior. Techniques to reduce the number of deer include decreasing the deer population or excluding deer from the roadway. Techniques used to change motorist behavior include reducing vehicle speed or increasing motorists' ability to see deer. Modifying deer behavior includes making the roadside less attractive to deer or frightening deer away from the roadway. Despite a limited amount of data, multiple studies have shown properly installed and maintained fences combined with wildlife crossings to be the most effective method of reducing DVCs. Methods with unproven effectiveness include: intercept feeding, repellents, reduced speed limits, caution signs, and roadway lighting. Stimuli designed to frighten deer (e.g., deer whistles, flagging, and deer reflectors) are ineffective because they cannot be perceived by deer or do not elicit a flight response. Well-designed studies are needed so that we can acquire the knowledge about how to reduce the frequency of DVCs.

Key words: deer, deer–vehicle collision, human–wildlife conflict, *Odocoileus* spp.

DEER–VEHICLE COLLISIONS (DVCs) are increasing in the United States and worldwide as traffic volume increases, more roads are constructed, and deer (*Odocoileus* spp.) habitat becomes more fragmented (Sullivan and Messmer 2003). Conover (2001) estimated that 1.5 million DVCs occur annually in the United States. These collisions translate into >29,000 human injuries, >200 human fatalities, 1.3 million deer fatalities, and >1 billion dollars in property damage per year (Conover 1997).

Despite the magnitude of this problem, there are relatively few studies that assess the effectiveness of measures to reduce DVCs. Previous studies often did not directly measure a technique's effectiveness in reducing DVCs; instead, they examined a technique's effectiveness on a related variable, such as vehicle speed, the number of deer using a crossing, or the number of deer observed along the roadside.

Given that DVCs are related to the number of deer and vehicles, a reduction in either may be expected to reduce the number of collisions. Transportation agencies have few opportunities to reduce the number of vehicles on roadways. However, a reduction in the number of deer is possible through a variety

of lethal and nonlethal methods or by making the road inaccessible to deer by fencing or other exclusion methods. Other methods to reduce DVCs involve changing or modifying either deer or motorist behavior. Changing motorist behavior includes reducing vehicle speed or increasing motorists' ability to see deer. Modifying deer behavior includes making the roadside less attractive to deer or frightening deer away from the roadway. In this study, we



Approximately 1.5 million DVCs occur each year in the United States.

reviewed the available literature on techniques aimed at reducing the number of DVCs.

Reducing deer numbers along roads

A reduction in the number of deer on the road can be expected to reduce the number of DVCs (Sullivan and Messmer 2003). This can be accomplished by reducing the deer population in a localized area or by excluding deer from the road.

Hunting or relocation

Several studies have reported that the implementation of hunting or deer-relocation programs reduced the number of DVCs (Ishmael et al. 1993, Jones and Whitham 1993, Doerr et al. 2001, Jenks et al. 2002, Sudharsan et al. 2006). Similarly, hunting restrictions have been correlated with increases in the number of DVCs (Kuser and Wolgast 1983). However, other studies have found no link between the number of DVCs and the size of deer populations (Case 1978, Waring et al. 1991). The diversity of these findings is likely a result of differences in deer population densities and dynamics between study areas. Despite this, reducing the number of deer may be effective in reducing the number of DVCs in a localized area (Danielson and Hubbard 1998, Sullivan and Messmer 2003, Hedlund et al. 2004). However, reducing the number of deer is a controversial management practice (Conover 1997). Even in areas of high numbers of DVCs, most people are opposed to decreasing the deer population (Conover 1997, Storm et al. 2007).

Fencing

Effectiveness of fencing. Several studies investigated the effect of fencing wildlife without crossing structures or escape routes along a newly-constructed Pennsylvania interstate highway in the 1960s and 1970s (Tubbs 1972, Puglisi et al. 1974, Bellis and Graves 1978, Falk et al. 1978, Feldamer et al. 1986). These studies found that unmaintained fencing was ineffective at keeping deer off the highway right-of-ways (ROWs) but were unable to draw definitive conclusions about the effects of fencing on the number of DVCs (Tubbs 1972, Falk 1975, Bellis and Graves 1978). It is important that fencing be regularly maintained (Ward 1982, Feldamer et al. 1986, Rosa 2006) because deer are quick

to exploit fence gaps >23 cm (Bellis and Graves 1978, Falk et al. 1978). In a study of the effectiveness of fencing, Clevenger et al. (2001) found that the erection of a 2.4-m-high fence on both sides of a highway reduced the number of DVCs by 20%.

Sufficiently high and long fencing ensures that deer cannot enter the ROW by either jumping over it or walking around it. Several studies have found 2.4-m- or 3.0-m-high fencing to be an effective barrier to deer (Reed et al. 1974, 1975; Ward 1982; Ludwig and Bremicker 1983; Seamans et al. 2003). Feldamer et al. (1986) found that white-tailed deer (*Odocoileus virginianus*) rarely jumped a 2.7-m high fence, but that deer were still able to enter the ROW by crawling underneath a fence. Angled wire extensions have been used to add height to fences, but these have resulted in increased deer entanglements (Putman 1997). Additionally, fencing of sufficient length discourages deer from detouring around the ends and into the ROW (Reed et al. 1975, 1979; Ward 1982). Studies have concluded that extending the length of fencing substantially reduces the number of "end runs" or the "end-of-the-fence problem" (Ward 1982, Clevenger 2001, Rosa 2006). Clevenger (2001) found that a high density of DVCs occurred where a 10-km fence ended. When the fence was extended an additional 16 km, the high density of DVCs moved to the new end of the fence. However, this problem was solved when this fence was extended an additional 18 km (Clevenger 2001).

Effectiveness of electric fencing. Studies have examined the effectiveness of electric fencing for deer exclusion, but no published studies have examined its effectiveness in reducing DVCs. One study, however, has examined the effect of electric fencing on the number of moose (*Alces americanus*) on the ROW and the number of moose-vehicle collisions (Leblond et al. 2007). This study found that the number of moose tracks on the ROW decreased 77% after the installation of an electric fence. It also found that areas with electric fence had 76% fewer tracks in the ROW than areas without fence. Additionally, no moose-vehicle collisions occurred after the electric fence was erected in areas where collisions had averaged 1.4 or 5.4 collisions per year prior to installation.

Effectiveness of deer guards. Cattle guards or metal bars installed flush with the road prevent cattle from entering a ROW via an interchange. Unfortunately, these structures are ineffective in inhibiting deer movement (Ward 1982), but deer guards have been developed for this purpose. Reed et al. (1979) examined the effect of 2.4-m-high fencing combined with 5 types of deer guards and found that none was effective. In contrast, Silvy and Sebesta (2000) developed a deer guard that, when used in conjunction with 2.8-m fencing, was 100% effective in trials with penned Florida Key deer (*Odocoileus virginianus clavium*). This speed-bump-shaped guard consisted of metal bars >2 cm apart placed perpendicular to the road. The bars gradually inclined from ground level to a height of 0.6 m and then declined back down to the roadway for a total length of 5.5 m. Another type of deer guard was 99% effective in trials with penned key deer when used in conjunction with 2.4 m fencing (Peterson et al. 2003). This guard, installed flush with the road, measured 6.1 m in length and consisted of a triangular grid with triangles measuring 10 cm, 12 cm, or 16 cm on a side. However, in a field test, Braden et al. (2005) found that the Peterson et al. (2003) deer guards allowed 6 deer to cross, although the number of crossing attempts was unknown.

Effectiveness of 1-way escape routes through fencing. Several studies have examined the effectiveness of fencing with the addition of 1-way escape routes that allow deer to exit a fenced ROW should they become trapped within the fencing. Many DVCs occur when deer become trapped within the fencing and cannot escape (Ludwig and Bremicker 1983). One type of 1-way escape route is a set of 1-way gates with openings that are lined with a series of metal tines to funnel the deer out of the ROW (Reed et al. 1974; Figure 1). Another type of 1-way escape route is an earthen escape ramp, which is a vegetated mound of soil located on the ROW side of the fence and placed against a 1.5 m wall installed within the 2.4 m fence. Deer exit the ROW by walking up the earthen incline and then jumping down 1.5 m to the outside of the fence. Ludwig and Bremicker (1983) concluded 1-way gates were effective in reducing DVCs when used in conjunction with 2.4 m high fencing. However, the authors' estimate of reduction in the number of DVCs



FIGURE 1: One-way gates allow deer to exit the roadway should they become trapped within the fencing.

was somewhat questionable because it was based upon an extrapolation of the number of DVCs on a different road prior to the tested road's construction. Unfortunately, 1-way gates are used only by a small percentage (16%) of deer that approach them trying to exit the ROW (Lehnert 1996). Bissonette and Hammer (2000) compared the effectiveness of earthen escape ramps to 1-way gates. They found that deer used escape ramps 8 to 11 times more often than they used 1-way gates and that DVCs decreased after installation of ramps.

Effectiveness of deer crosswalks, underpasses, and overpasses. Sometimes deer have to cross roads in order to survive (e.g., when the road separates their winter and summer range). In these cases, fences become barriers that decrease landscape permeability and isolate deer populations. In order to maintain landscape permeability while allowing deer to cross the road safely, several different designs have been used. These include deer crosswalks built on the road's surface, deer underpasses that allow deer to pass under the road (e.g., culverts, tunnels, and bridges), and deer overpasses that allow deer to pass over the road (i.e., bridges).

Lehnert and Bissonette (1997) examined the effectiveness of deer crosswalks in conjunction with 2.3-m-high fencing to reduce DVCs. This design used fencing to funnel deer to an opening in the fence where it was intended that they follow a dirt path bordered by cobblestones (that they were expected not to cross) to the road's edge. The deer then crossed the road and exited through an identical setup. Crossing areas were delineated with white

paint, and signs alerted motorists to crossing deer. Crosswalks in conjunction with fencing decreased DVCs as much as 42%, although a lack of replication did not allow for definitive conclusions. Further evaluation showed that crosswalks do not work on high-volume roads but may work on low-volume roads when combined with animal-activated signs (J. A. Bissonette, Utah State University, personal communication).

Deer underpasses come in a variety of sizes, and designs (e.g., box, circular, and elliptical culverts, as well as bridged underpasses), and all are constructed to allow deer to pass under the road. Design choices are important to keep deer from being involved in DVCs. Utilization of underpasses by deer has been linked to many factors, including the structure's height, length, and width. However, incomplete knowledge of these factors makes the design of an effective underpass difficult (Forman et al. 2003).

Underpasses have been constructed in a variety of sizes (Reed et al. 1975, Clevenger 1998, Clevenger and Waltho 2000, Forman et al. 2003), but heights >2.4 m and widths >6 m are recommended (Foster and Humphrey 1995, Forman et al. 2003, Gordon and Anderson 2003). Deer seem to prefer more open underpasses, and an openness factor (calculated as the entrance's area divided by its length) has been used to design effective underpasses (Reed et al. 1975, Ward 1982, Putman 1997, Gordon and Anderson 2003). Mule deer (*Odocoileus hemionus*) are reluctant to use underpasses with openness factors of 0.6 (Reed et al. 1979), but are more willing to use underpasses with openness factors of >0.8 (Gordon and Anderson 2003).

Deer overpasses are bridges that are designed to allow deer to pass over a ROW. They are covered with vegetation and are generally rectangular or hourglass in shape. The willingness of deer to use them depends on the structure's height, length, and width. The width of the structure seems to be the most important factor (Reed et al. 1979, Knapp et al. 2004). Rodriguez et al. (1997) and Forman et al. (2003) recommended that overpasses have widths of >30 m. A bridge-effect factor (calculated as one half the bridge's width multiplied by its height, divided by its length), analogous to an underpass-openness factor, has been developed for these structures as a guide for meeting wildlife preferences

(Knapp et al. 2004). Deer are somewhat hesitant to cross overpasses with factors of 0.34 and 0.65, but structures with factors of 0.26 also have been considered successful in facilitating passage (Reed et al. 1979, Knapp et al. 2004).

To be effective, the location of a crossing structure is critical (Foster and Humphrey 1995, Clevenger 1998, Clevenger and Waltho 2000, Forman et al. 2003, Barnum 2004); yet, information on the proper placement of crossings is scarce (Forman et al. 2003). Some studies have concluded that crossings should be constructed where high numbers of DVCs occur (Danielson and Hubbard 1998) or where wildlife corridors intersect roads (Foster and Humphrey 1995, Bruinderink and Hazebroek 1996). Others have recommended that crossing locations should be evaluated on an individual basis and that habitat conductivity be considered (Barnum 2004, Knapp et al. 2004).

Other factors associated with a crossing's effectiveness include the ability of a deer standing at the entrance of a crossing to be able to see the exit on the other side (Knapp et al. 2004), the amount of human activity (Clevenger 1998, Clevenger and Waltho 2000, Phillips et al. 2001), and the presence of woody cover at entrance and exit points (Putman 1997, Rodriguez et al. 1997, Danielson and Hubbard 1998, Clevenger and Waltho 2000, Ng et al. 2004). Additionally, several studies have shown a crossing's substrate to be particularly important (Ward 1982, Putman 1997). An overpass with a landscaped surface or an underpass with a dirt floor are used more often than crossings with manufactured substrates, such as concrete (Clevenger and Waltho 2000, Ng et al. 2004). In the only comparison of deer-use of overpasses and underpasses, overpasses were preferred (Clevenger et al. 2001).

Several studies have documented the effectiveness of crossings in conjunction with fencing and escape routes in decreasing the number of DVCs. Reed et al. (1979) found that various combinations of 2.4-m-high fence, overpasses, underpasses, and 1-way gates reduced DVCs an average of 78%. Ward (1982) examined the effect of 2.4-m-high fencing combined with underpasses and 1-way gates on the number of DVCs. The installation of these structures and fencing resulted in a >90% reduction in the number of DVCs from pre-installation

levels. Similarly, Rosa (2006) found that the installation of 2.4-m-high fences in conjunction with underpasses, 1-way gates, and earthen escape ramps were effective in decreasing DVCs by 77%. Woods (1990) examined the effect of the installation of 2.4-m-high fence with overpasses, underpasses, and 1-way gates on the number of DVCs. This installation resulted in a 95% decrease in the number of DVCs.



Reducing vehicle speed is one technique used to reduce the number of DVCs.

Modify motorist behavior

Reducing the number of deer on the road is not the only way to reduce the number of DVCs. Another option is modifying motorist behavior by reducing vehicle speed or increasing motorists' ability to see and avoid deer in the road. Several techniques have been examined, including the installation of roadway lighting, signs, and the clearing of vegetation along the ROW so that deer will be more conspicuous to drivers.

Reducing the speed limit

Studies have tested for correlations between speed limits (Bashore et al. 1985, Gunther et al. 1998) or average vehicle speed and the number of DVCs (Allen and McCullough 1976, Case 1978), but no studies have actually tested whether decreasing the speed limit on a highway actually decreased the frequency of DVCs. However, Bertwistle (1999) examined the effect of speed limit reductions on the number of vehicles colliding with big horned sheep (*Ovis canadensis*) and elk (*Cervus canadensis*). Surprisingly, he found that reducing speed limits increased the number of sheep and elk collisions with vehicles in 4 of 5 cases. The author speculated that increased traffic volumes may have been responsible for the increase in collisions.

Road sign installation

Signs that alert motorists to the presence of deer can be grouped into 5 categories: caution signs, enhanced caution signs, temporary signs, dynamic-message signs, and animal-activated warning systems. The use of signs is widespread

even though their effectiveness is often questionable.

Caution signs. Simple caution signs (i.e., yellow, diamond-shaped signs with black deer silhouettes at their centers) are the most frequently-used method to decrease DVCs (Romin and Bissonette 1996, Sullivan and Messmer 2003). Many authors have noted, however, that these signs are so prevalent along roads that motorists ignore them (Putman 1997, Sullivan and Messmer 2003). Stanley et al. (2006) showed that 30% of participants failed to see a deer caution sign. Aberg (1981), as cited by Hedlund et al. (2004), found that the presence of caution signs did not increase the likelihood that passing motorists would observe moose decoys alongside the road. Regardless of these findings, 76% of survey participants said that deer caution signs increased their alertness (Stout et al. 1993). However, no studies to date have examined the direct effect of caution signs on the number of DVCs.

Enhanced caution signs. Many deer caution signs have been enhanced in some way to increase the likelihood that motorists will see and react to them. Pojar et al. (1972) found that there were no differences in vehicle speed between 2 types of enhanced caution signs: a yellow diamond with the words "Deer Xing" illuminated with neon tubing and a yellow diamond with 4 deer silhouettes sequentially illuminated with neon tubing from left to right. There were also no differences in vehicle speeds between the signs when they were visible and when they were not. Additionally, Pojar et al. (1975) found no difference in the number of DVCs, whether a neon deer silhouette sign was displayed or not. There was also no difference in the number of DVCs when a modified caution sign displaying a car silhouette encountering a deer silhouette and the words "High Crash Area" mounted below it was present (Rodgers 2004). However, vehicle speeds decreased 13 km/hr when a deer carcass was present in the highway's emergency lane (Pojar et al. 1975).

Temporary signs. Sullivan et al. (2004) examined the effect of 2 types of enhanced temporary

deer signs on vehicle speed and the number of DVCs. Signs were erected only during a short period in the fall and spring when mule deer (*Odocoileus hemionus*) were migrating through the study area. The erection of these signs decreased the percentage of speeding vehicles from 19% to 8% and decreased DVCs by an estimated 50% (Sullivan et al. 2004).

Dynamic message signs. Dynamic message signs, or variable message signs, are electronic signs typically with a black background and amber lettering. Such signs are either mounted permanently above the roadway or positioned on portable trailers beside the roadway. Hardy et al. (2006) found that messages displayed on such signs that alerted motorists to wildlife were associated with lower speeds than either a sign displaying highway information or a sign with no message. They also found that portable signs were correlated with a greater reduction in speed than were permanent signs (Hardy et al. 2006).

Stanley et al. (2006) used a driving simulator to examine the effect of 4 different sign combinations on vehicle speed, braking distance, sign detection, and the number of DVCs. They found that enhanced signs (caution signs with flashing lights, dynamic message signs, and a combination of both) decreased speeds (6 km/hr, 8km/hr, and 5 km/hr, respectively) compared to caution signs without lights. However, they did not detect a significant difference in the number of simulated DVCs between types.

Animal-activated warning systems. Animal-activated warning systems detect wildlife on the roadside and then flash warning lights or turn on signs that alert drivers to the animal's presence. Systems are activated by a variety of mechanisms, including the detection of seismic ground vibrations, infrared radiation, or the breaking of a microwave, laser, or infrared beam as an animal passes through an area adjacent to the road. Although numerous systems have been erected and tested in Europe, the United States, and Canada, data on these systems' effectiveness in reducing DVCs are



Familiar deer caution signs alert motorists to the presence of deer.

scarce (Huijser et al. 2006). However, there is evidence that drivers slow down in response to an activated system (Gordon and Anderson 2002, Gordon et al. 2003, Hammond and Wade 2004), and a reduction in speed, along with increased driver alertness, may decrease the number of DVCs (Huijser et al. 2006). In the only published study to evaluate a system's effectiveness in reducing animal-vehicle collisions, Mosler-Berger and Romer (2003, as cited in Huijser et al. 2006) reported that a series of infrared activated systems in Switzerland succeeded in reducing the number of collisions by about 80%.

Public education

Programs aimed at educating the public about the danger of DVCs and how to avoid them are used by half of U.S. states to reduce DVCs (Romin and Bissonette 1996). These programs include newspaper, radio, television, and website announcements (Rodgers 2004). The effectiveness of these programs is unknown, although Knapp et al. (2004) and Rodgers (2004) suggest that campaigns providing specific information (e.g., mule deer migration times and locations) are more likely to be effective than those that provide general education.

Lighting

Most (80% to 95%) DVCs occur between sunset and sunrise (Carbaugh et al. 1975, Allen and McCullough 1976, Reed and Woodard 1981, Schafer and Penland 1985). Hence, street lights may enhance motorists' ability to see a deer in sufficient time to avoid it. However, Reed and Woodard (1981) found that lighting had no effect on DVCs.

Vegetation

Clearing obstructive vegetation from the ROW may increase motorists' abilities to see deer standing along the road. Lav Sund and Sandergrén (1991) found that clearing a 20-m zone on each side of the highway decreased moose-vehicle collisions by almost 20%. Unfortunately, the removal of roadside vegetation also raises

other issues, including aesthetics, maintenance costs, and ecological impacts (Hedlund et al. 2004, Donaldson 2006).

In-vehicle detection systems

New technologies that may decrease DVCs include systems that employ infrared or night vision devices to enhance motorists' abilities to detect wildlife in the road. Two systems currently available are Cadillac Night Vision™ (General Motors Corporation, Detroit, Mich.) developed for cars, and Bendix Xvision™ (Honeywell International Inc., Morristown, N. J., and Raytheon Company, Waltham, Mass.) available for commercial trucks and buses (Knapp et al. 2004). These systems use thermal imaging to detect and then display images of the road ahead, enabling a driver to see 3 to 5 times farther than they could with typical low-beam headlamps (Schreiner 1999). Intuitively, it seems that this technology may reduce DVCs; however, its ability to decrease DVCs has not been tested.

Modify deer behavior

Another way to reduce DVCs is to modify deer behavior. This can be accomplished either by making the roadside less attractive to deer or frightening deer away from the roadway.

Nutritional resources

Vegetation. Many authors have suggested that the presence of palatable vegetation along the ROW and maintenance practices (e.g., mowing) which increase this vegetation's palatability may also increase the number of deer foraging along ROWs (Putman 1997, Farrell et al. 2002, Knapp et al. 2004, Donaldson 2006). Cultivating unpalatable plants along ROWs may therefore decrease DVCs. However, the ability of these changes to decrease DVCs has not been evaluated.

Providing supplemental food. Intercept feeding is the provisioning of supplemental food to divert deer from feeding along the ROW or crossing the road to reach feeding areas. In 33% of comparisons of areas where supplemental food was provided and areas where it was not, Wood and Wolfe (1988) found that intercept feeding reduced the frequency of DVCs by <50%. They recommend its use in conjunction

with fencing and only for short periods of time to mitigate costs and avoid deer becoming resource-dependent.

Reducing the use of or providing supplemental salt. Many states use road salt to keep roads clear of snow. However, road salt may attract deer to a highway's ROW to satisfy their need for salt. Many authors have speculated that the use of road salt may increase the likelihood of a DVCs (Fraser and Thomas 1982, Feldamer et al. 1986, Bruinderink and Hazebroek 1996, Forman and Alexander 1998). Fraser and Thomas (1982) found that moose–vehicle collisions were more likely to occur <100 m from road salt puddles than expected randomly. However, no studies have documented similar correlations between locations of DVCs and salt puddles or whether reductions in the use of road salt, the use of salt alternatives, or the placement of salt licks away from the road are effective in reducing the number of DVCs.

Repellents

Placing whistles on vehicles. Deer whistles are noise makers attached to a vehicle to frighten deer away from the road. When vehicles reach speeds >48 km/hr the whistle sounds. Studies have found that deer hearing is most sensitive in the range of 2–6 kHz (Scheifele et al. 2003) or 4–8 kHz (D'Angelo et al. 2007). Tested whistles, however, emitted frequencies both inside (3 kHz) and outside (12 kHz) these hearing ranges (Scheifele et al. 2003). D'Angelo et al. (2007) calculated that under ideal conditions, a whistle would need to emit 100 dB sound pressure level at 1 m to be heard 100 m from a vehicle. However, whether this distance would allow deer to avoid being hit by a vehicle is unknown (D'Angelo et al. 2007). This conclusion was corroborated by Romin and Dalton (1992) who found that the reactions of deer to vehicles equipped with whistles and to those without them were similar. Despite this, deer whistles continued to be used nationwide (Romin and Bissonette 1996, Sullivan and Messmer 2003).

Placing deer flags along the ROW. When alarmed, white-tailed deer (*Odocoileus virginianus*) raise, or flag, their tail, exposing the conspicuous white underside. Bashore (1975) found that erecting 2-dimensional silhouettes of deer displaying flagging behavior along a road was



Approximately 80% to 90% of DVCs occur at night.

ineffective at keeping deer away from the road and decreasing DVCs.

Placing deer reflectors along the ROW. Deer reflectors deflect light from an approaching vehicle's headlights onto the side of the road. Such reflectors are advertised as an effective method for scaring away deer that are approaching the road or that are in the ROW (Romin and Dalton 1992). VerCauteren et al. (2006) found that deer were unable to see red light and that green and blue light did not frighten deer. Other studies found that reflected light did not change deer behavior in a way that would decrease DVCs (Zacks 1986, Armstrong 1992, Ujvari et al. 1998, D'Angelo et al. 2006). Cottrell (2003) found there was no difference in the number of DVCs between sites where reflectors were present or absent. Additional studies have also found that reflectors are ineffective at reducing DVCs (Waring et al. 1991, Ford and Villa 1993, Reeve and Anderson 1993, Rodgers 2004). In contrast, Schafer and Penland (1985) found that reflectors were effective; 52 deer were killed when reflectors were absent and 6 were killed when they were present. However, only 4 sections of road were used, and control sections were not independent of test sections. Pafko and Kovach (1996) found that the installation of reflectors reduced DVCs in rural areas but increased them in urban areas. Again, control sections were not independent of test sections, and the number of DVCs prior to installation was estimated for the rural areas.

Using chemical repellents. A plethora of studies has evaluated the effectiveness of chemical repellents on deer behavior (El Hani and Con-

over 1997). Repellents have been applied to roadside vegetation in an effort to reduce DVCs in British Columbia and Germany (Putman 1997, Danielson and Hubbard 1998, Hedlund et al. 2004, Knapp et al. 2004). However, their effectiveness in reducing DVCs has not been demonstrated (Putman 1997, Hedlund et al. 2004, Knapp et al. 2004).

Roadway planning

A final way to reduce DVCs is to consider the impact of roadway design on DVCs during the planning process. Decisions such as road location, number of lanes, and road curvature may impact the number of DVCs (Knapp et al. 2004, Donaldson 2006). Data on deer habitat, migration routes, and the locations of DVCs in preexisting area roads that were supplied to planners prior to the initiation of the roadway design and planning may be helpful in the construction of roads that will reduce the number of DVCs (Singleton and Lehmkuhl 2006, Donaldson 2006). Studies have shown that DVCs are spatially correlated to landscape elements that deer likely travel, and a road design that takes this into account may result in fewer DVCs (Hussain et al. 2007). For example, it may be helpful for planners to consider that deer often travel along waterways and to design bridges that not only span waterways but also allow enough room for deer to pass under the bridge without their having to venture into the water (Donaldson 2006). Bridges that do not provide a dry passageway for deer may force deer over the road, and the result would be a location with increased DVCs (Romin 1994, Finder et al. 1999, Donaldson 2006).

Conclusion

DVCs are a serious problem in many parts of the world. The results of studies examining the effectiveness of measures to reduce DVCs often have a high level of uncertainty and a low strength of inference (Roedenbeck et al. 2007). Reasons for this include study designs that do not collect data before, during, and after a technique is implemented; designs that do not compare control sites to sites where a technique is implemented both before and after implementation; and studies that lack replicate sites (Roedenbeck et al. 2007). Study designs that

meet these standards, however, are not always possible (e.g., control sites are unavailable, no data prior to a technique's implementation exist, or financial resources limit the scope of the experiment; Rodenbeck et al. 2007). One result of this is that substantial amounts of time, money, and effort have been expended on the implementation of dubious methods of reducing DVCs, such as deer whistles, deer flagging, deer reflectors, and permanent deer caution signs.

At present, the best way to reduce DVCs is to properly install and maintain deer-proof fences with wildlife crossings (Reed et al. 1979, Ward 1982, Woods 1990, Rosa 2006). This technique restricts deer access to the ROW, while maintaining landscape permeability and reducing DVCs (Foster and Humphrey 1995, Clevenger et al. 2001, Ng et al. 2004). Unfortunately, the construction and maintenance of this technique is costly and not appropriate for all locations. Additionally, questions about application (e.g., crossing location) and design (e.g., crossing size) still exist (Forman et al. 2003). Finally, once installed, fences must be constantly checked and maintained so that new gaps do not allow deer access to the ROW.

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